# Building Skills in Object-Oriented Design

## Step-by-Step Construction of A Complete Application

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# Preface

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The present letter is a very long one, simply because I had no leisure to make it shorter.

--BLAISE PASCAL , *Pensées*, The Provincial Letters , provincial letter 16, p. 571.

## Why Read This Book?

The coffee-shop answer is to provide the beginning designer with a sequence of interesting and moderately complex exercises in OO design.

Some software developers find themselves stalled when trying to do object-oriented (OO) design. As programmers, they've understood the syntax of a programming language, and pieced together small examples. However, it is often difficult to take the next step to becoming a designer. Because this transition from guided learning of language features to self-directed design work is often ignored, programmers are left to struggle through their first design projects without appropriate skills or support. While it is critically important to examine examples of good design, a finished product doesn't reveal the author's decision-making process that created the design.

The most notable consequence of this skills gap is the creation of software that is far more complex than necessary to effectively solve a given problem. This, in turn, leads to software with high maintenance costs stemming from the low quality. It also leads to an unfair indictment of OO technology; this is usually voiced as “we tried OO programming and it failed.”

As programming team leaders, educators and consultants, we find that software development training is focused on the programming tools, but does not expose the process of creating a design. In the building trades, we would neither expect nor allow apprentice plumbers to design the sanitary sewage system for an urban office building. Yet, in too many *Information Technology* (IT) departments, software developers are expected to leap from basic training in their tools to application design.

To continue this rant, we also find that some managers are entrusted with significant projects, but are uncomfortable with OO design on modern high-performance hardware. They tend to focus their design energies on the kinds of software architectures that were appropriate when the enterprise owned a single computer, when 64 megabytes of memory was all the enterprise would ever need, and centralized disk storage was charged back to end user departments at a rate of pennies per track per month. In some organizations, there are a few enduring symptoms of this mind set in some of the ways that “end-user computing” is separated from “enterprise computing”; we relegate everything non-mainframe to second class status.

Management discomfort with OO technology surfaces in many ways. One shocking comment was that “no application needs more than six classes.” A consequence of this management attitude is an unrealistic expectation for schedule and the evolution of the deliverables.

The intent of this book is to help the beginning designer by giving you a sequence of interesting and moderately complex exercises in OO design. This book can also help managers develop a level of comfort with the process of OO software development. The applications we will build are a step above trivial, and will require some careful thought and design. Further, because the applications are largely recreational in nature, they are interesting and engaging. This book allows the reader to explore the processes and artifacts of OO design before project deadlines make good design seem impossible.

We hope to prevent managers from saying the following: “We had a good design, but were forced to compromise it to meet our schedule.” As consultants, we find this to be a sad statement of management's emphasis of one near-term goal over long-term value. In one case, this was the result of a series of poorly-informed management decisions compounded on weak design skills. One of the root causes was the inability of the designers and managers to agree to a suitable course of action when a new kind of requirement made devastating changes to an existing design. We believe that more informed managers would have made a decision that created better long-term value.

## Audience

Our primary audience is programmers who are new to OO programming. Have you found your first exposure to objects to be more distasteful than empowering? Why does this happen? Some instructors launch into extensive presentations on object orientation before getting to the language fundamentals, leaving students lost as to how they will accomplish the noble and lofty goals of OO. Other instructors leave OO for last, exposing the procedural side of the language first, and treating objects as a kind of add-on. This leaves students feeling that objects are optional. Additionally, some very skilled instructors are not skilled developers, and will often show examples that don't reflect currently accepted best practices.

Our audience has an exposure to the language, but needs more time to understand objects and object-orientation. We want to provide exercises that have four key features: just complex enough to require careful design work, just fun enough to be engaging, easy enough that results are available immediately, and can be built in simple stages.

In our effort to support the beginning student, we'll provide a few additional details on language features. We'll mark these as “Tips” for the new programmer, and qualify the tip by language. For more advanced students, these tips will be review material. We will not provide a thorough background in any programming language. The student is expected to know the basics of the language and tools.

Helpful additional skills include using one of the various unit test and documentation frameworks available. We've included information in the appendices.

Instructors are always looking for classroom projects that are engaging, comprehensible, and focus on perfecting language skills. Many real-world applications require considerable explanation of the problem domain; the time spent reviewing background information detracts from the time available to do the relevant programming. While all application programming requires some domain knowledge, the idea behind these exercises is to pick a domain that many people know a little bit about. This allows an instructor to use some or all of these exercises without wasting precious classroom time on incidental details required to understand the problem.

This book assumes an introductory level of skill in an OO programming language. We provide specific examples in Java (at least version 1.4) and Python (at least version 2.5). Student skills we expect include the following.

- Create source files, compile and run application programs. While this may seem obvious, we don't discuss any integrated development environment (IDE). We have to assume these basic skills are present.
- Use of the core procedural programming constructs: variables, statements, exceptions, functions. We will not, for example, spend any time on design of loops that terminate properly.
- Some exposure to class definitions and subclasses. This includes managing the basic features of inheritance, as well as overloaded method names. We will avoid Python-unique features like multiple inheritance and callable objects, and focus on that subset of Python features that map directly to Java. For the Python equivalent of overloaded methods, we will assume that Python programmers can make use of default parameter values and named parameters.
- Some exposure to the various collections frameworks. For Java programmers, this means the classes in the `java.util` package. For Python programmers, this means the built-in sequence and mapping types.
- Optionally, some experience with a unit testing framework. See the appendices for supplemental exercises if you aren't familiar with Python's `unittest` or `doctest` or Java's `JUnit`.
- Optionally, some experience writing formal documentation. For Java programmers, this means javadoc comments. For Python programmers, this often means `Epydoc` or a similar documentation package. See the appendices for supplemental exerises if you aren't familiar with formal, deliverable documentation.

## Organization of This Book

This book presents a series of exercises to build simulations of the common, popular casino table games: *Roulette*, *Craps* and *Blackjack*. Each simulation can be extended to include variations on the player's betting system. With a simple statistical approach, we can show the realistic expectations for any betting system. Each of these games has a separate part in this book. Each part consists of a number of individual exercises to build the entire simulation. The completed project results in an application that can provide simple tabular results that shows the average losses expected from each betting strategy.

The interesting degree of freedom in each of the simulations is the player's betting strategy. The design will permit easy adaptation and maintenance of the player's strategies. The resulting application program can be extended by inserting additional betting systems, which allows exploration of what (if any) player actions can minimize the losses.

For Roulette, we proceed slowly, building up the necessary application one class at a time. Since this is the simplest game, the individual classes reflect that simplicity. We focus on isolation of responsibilities, creating a considerable number of classes. The idea is to build skills in object design by applying those skills to a number of classes.

The first chapter of the part provides details on the game of Roulette and the problem that the simulation solves. The second chapter is an overview of the solution, setting out the highest-level design for the application software. This chapter includes a technique for doing a *“walk-through”* of the design to be confident that the design will actually solve the problem.

Each of the remaining sixteen chapters is a design and programming exercise to be completed by the student. Plus or minus a Frequently Asked Questions (FAQ) section, each chapter has the same basic structure: an overview of the components being designed, some design details, and a summary of the deliverables to be built. The overview section presents some justification and rationale for the design. This material should help the student understand why the particular design was chosen. The design section provides a more detailed specification of the class or classes to be built. This will include some technical information on Java or Python implementation techniques.

For Craps, we build on the design patterns from Roulette. Craps, however, is a stateful game, so there is a more sophisticated design to handle the interactions between dice, game state and player. We exploit the **State** design pattern to show how the design pattern can be applied to this simple situation.

The first chapter is background information on the game of Craps, and the problem that the simulation solves. The second chapter is an overview of the solution, setting out the highest-level design for the application software. This chapter also provides a *“walk-through”* of the design.

Each of the remaining eleven chapters is an exercise to be completed by the student. Each chapter has the same basic structure: an overview of the component being designed, some design details, and a summary of the deliverables to be built.

The most sophisticated game that we cover here is Blackjack. The game states are more sophisticated than Craps since the available betting opportunities can change with split hands. Further, the player has two kinds of choices: betting opportunities, plus play opportunities. This makes the player's strategy considerably more complex. In casino gift shops, you can buy small summary cards that enumerate all possible game states and responses. The more advanced student can tackle these sophisticated betting strategies. For the less advanced student we will simplify the strategies down to some simpler conditions.

The first two chapters are background information on the game of Blackjack, the problem that the simulation solves, and an overview of the solution, setting out the highest-level design for the application software. Each of the remaining six chapters is an exercise to be completed by the student. Since this is more advanced material, and builds on previous work, this part has many simple deliverables compressed into the individual chapters.

## Why This Subject?

Casino table games may seem like an odd choice of subject matter for programming exercises. We find that casino games have a number of advantages for teaching OO design and OO programming.

- Casino games have an almost ideal level of complexity. If they were too simple, the *house edge* would be too obvious and people would not play them. If they were too complex, people would not enjoy them as simple recreation. Years (centuries?) of experience in the gaming industry has fine-tuned the table games to fit nicely with the limits of our human intellect.

- *Simulation* of discrete phenomena lies at the origin of OO programming. We have found it easier to motivate, explain and justify OO design when solving simulation problems. The student can then leverage this insight into other applications of OO programming for more common transactional applications.

- The results are sophisticated but easy to interpret. Probability theory has been applied by others to develop precise expectations for each game. These simulations should produce results consistent with the known probabilities. This book will skim over the probability theory in order to focus on the programming. For a few exercises, the theoretical results will be provided to serve as checks on the correctness of the student's work.

This book does not endorse casino gaming. Indeed, one of the messages of this book is that all casino games are biased against the player. Even the most casual study of the results of the exercises will allow the student to see the magnitude of the *house edge* in each of the games presented.

## Programming Style

We have to adopt a *style* for each of the languages we're presenting. We won't present a complete set of *coding standards*; we will omit a number of issues that should be standardized. Some IT shops have documents they call “coding standards”, but are little more than descriptive style guides. What follows is not this kind of style guide; instead, it is some justification of the style we use for the examples in this book.

Just to continune this rant, we find that source code examples speak louder than any gratuitously detailed “specification” of the desired style. We find that some IT organizations waste time trying to write definitions of the preferred style. A good example trumps the description of the example. In particular, as consultants, we are often asked to provide standards to an inexperienced team of programmers. While the programmers only look at the examples (often cutting and pasting them), some managers prefer to spend money on empty verbiage peripheral to the useful example.

We use Java-centric terminology -- “field” and “method” -- throughout the book. Occaisionally, we will emphasize the differences between Java and Python by using the Python terms “attribute”, “instance variable” or “method function”.

We avoid using complex prefixes for variable names. In particular, we find prefixes to be little more than visual clutter. For example, an integer parameter with the amount of a bet might be called `pi_amount` where the prefix indicates the scope (*p* for a parameter) and type (*i* for an integer).

This style of name is only appropriate for primitive types, and doesn't address complex data structures well at all. How does one name a parameter that is a LinkedList of Sets of Outcomes? In Java programs, the variables are formally declared, therefore, we find that we don't need additional cues for their data type.

In some cases, prefixes are used to denote the scope of an instance variables. Variable names might include a cryptic one-letter prefix like “f” to denote an instance variable; sometimes programmers will use “my” or “the” as an English-like prefix. We prefer to reduce clutter. In Java, we have the qualifier `this.` available to disambiguate parameter from instance variable references. In Python, instance variables are always qualified, typically by `self.`, making the scope very clear.

## Conventions Used in This Book

Code examples will be minimal, and will include Python and Java. Here is a Python example.

### Example 1. Typical Python Example

```
combo = { } ❶
for i in range(1,7):
    for j in range(1,7):
        roll= i+j
        combo.setdefault( roll, 0 ) ❷
        combo[roll] += 1
for n in range(2,13):
    print "%d %.2f%%" % ( n, combo[n]/36.0 ) ❸
```

❶ This creates a Python dictionary, a map from key to value. If we initialize it with something like the following: `combo = dict( [ (n,0) for n in range(2,13) ] )`, we don't need the `setdefault` function call below.

❷ This assures that the rolled number exists in the dictionary with a default frequency count of 0.

❸ Print each member of the resulting dictionary. Something more obscure like `[ (n,combo[n]/36.0) for n in range(2,13)]` is certainly possible.

The output from the above program will be shown as follows:

```
2 0.03%
3 0.06%
4 0.08%
5 0.11%
6 0.14%
7 0.17%
8 0.14%
9 0.11%
10 0.08%
11 0.06%
12 0.03%

Tool completed successfully
```

We will use the following type styles for references to a specific `Class`, `method`, or `variable`.

Most of the design specifications will provide Java-style method and variable descriptions. Python doesn't use type specifications, and Python programmers will have to translate the Java specifications into Python by removing the type names.

### Sidebars

When we do have a significant digression, it will appear in a sidebar, like this.

### Tip

There will be design tips, and warnings, in the material for each exercise. These reflect considerations and lessons learned that aren't typically clear to starting OO designers.

## Acknowledgements

We would like to thank Chuck Pyrak for putting us up to this. His idea of a One Room Schoolhouse to teach Java to an audience at multiple skill levels was a great idea. Additionally, our colleagues who collaborated through BLOKI brought infinte wisdom and insight to a complex and difficult project.

Thanks to Dion Dock for detailed, thoughtful comments.

# Chapter 1. Foundations

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We'll set our goal by presenting several elements that make up a complete *problem statement*: a *context* in which the problem arises, the *problem*, the *forces* that influence the choice of solution, the *solution* that balances the forces, and some *consequences* of the chosen solution.

Based on the problem statement, we'll present the high-level use case that this software implements. The use case is almost too trivial to bother defining. However, we have seen many projects run aground because they lacked even the most rudimentary description of the actor, the system and how the system helps the actor create value.

We will summarize the approach to the solution, describing the overall strategy that we will follow. This is a kind of overall design pattern that we'll use to establish some areas of responsibility.

We will also describe the technical foundations. In this case, they are not terribly complex, but this is an important part of describing any software solution, no matter how simple.

We will dance around the methodology issue. Our intent is not to sell a particular methodology, but to provide some perspective on how we broke the work into manageable pieces.

Finally, we'll present some important parts of getting started on the solution. These are more specific, technical considerations that define common aspects of our approach.

## Problem Statement

**Context.** Our context is the “classic” casino table games played against the house, including Roulette, Craps and Blackjack. We want to explore the consequences of various betting strategies for these casino games. Questions include “How well does the Cancellation strategy work?” “How well does the Martingale strategy works for the Come Line odds bet in Craps?” “How well does this Blackjack strategy I found on the Internet compare with the strategy card I bought in the gift shop?”

A close parallel to this is exploring variations in rules and how these different rules have an influence on outcomes. Questions include “What should we do with the 2x and 10x odds offers in Craps?” “How should we modify our play for a single-deck Blackjack game with 6:5 blackjack odds?”

Our context does not include exploring or designing new casino games. Our context also excludes multi-player games like poker. We would like to be able to include additional against-the-house games like Pai Gow Poker, Caribbean Stud Poker, and Baccarat.

**Problem.** Our problem is to answer the following question: *For a given game, what player strategies produce the best results?*

**Forces.** There are a number of forces that influence our choice of solution. First, we want an application that is relatively simple to build. Instead of producing an interactive user interface, we will produce raw data and statistical summaries. If we have little interaction, a command-line interface will work perfectly. We can have the user specify a player strategy and the application respond with a presentation of the results. If the results are tab-delimited, they can be pasted into a spreadsheet for further analysis.

Another force that influences our choice of solution is the need to be platform and language agnostic. In this case, we have selected an approach that works well on POSIX-compliant operating systems (i.e., Linux, MacOS, and all of the proprietary UNIX variants), and also works on non-compliant operating systems (i.e., all of the Windows versions). We have chosen two OO languages that work identically on both platform families: Java and Python.

We also need to strike a balance between interesting programming, probability theory and statistics. On one hand, the simplicity of these games means that complete analyses have been done using probability theory. However, that's not a very interesting programming exercise, so we will ignore the pure probability theory route in favor of learning OO design and programming.

Another force is the desire to reflect actual game play. While a long-running simulation of thousands of invidual cycles of play will approach the theoretical results, people typically don't spend more than a few hours at a table game. If, for example, a Roulette wheel is spun once each minute, a player is unlikely to see more that 480 spins in an 8-hour evening at a casino. Additionally, many players have a fixed budget, and the betting is confined by table limits. Finally, we need to address the subject of “money management”: a player may elect to stop playing when they are ahead. This structures our statistical analysis: we must simulate sessions of play that are limited in time, the amount lost and the amount won.

**Solution.** Our overall goal is to produce an application that allows us to experiment with different casino game betting strategies. We'll build a simple, command-line simulator that provides a reliable, accurate model of the game. We need to be able to easily pick one of a variety of player betting strategies, play a number of simulated rounds of the game, and produce a statistical summary of the results of that betting strategy.

**Consequences.** One of the most important consequences of our solution is that we will build an application into which new player betting strategies can be inserted. Clever gamblers invent new strategies all the time. We will not know all of the available strategies in advance, so we will not be able to fully specify all of the various design details in advance. Instead, we will find ourselves reworking some parts of the solution, to support a new player betting strategy. This forces us to take an *agile* approach to the design and implementation.

## The Use Case

We have a single, small *use case*. We have some opinions on what makes a useful use case in our Soapbox on Use Cases. There is a single *actor*, the “investigator”. The actor's goal is to see the expected results of using a particular strategy for a particular game. The typical scenario is the following.

**Procedure 1.1. Basic Use Case**

1. **Actor**

   Specifies which game and betting strategy to test. The strategy may need additional parameters, like an initial budget, or *stake*. The game may require additional parameters, like betting limits.

2. **System**

   Responds with a statistical summary of the outcomes after a fixed number of cycles (spins, or throws or hands). The number of cycles needs to be small (on the order of 200, to reflect only a few hours of play).

### Soapbox on Use Cases

We feel that the use case technique is badly abused by some IT organizations. Quoting from Jacobson95, “A use case is a sequence of transactions in a system whose task is to yield a result of measurable value to an individual actor of the system.”

A use case will clearly identify an actor, define the value created, and define a sequence of transactions. A use case will be a kind of system test specification. A use case will define the system's behavior, and define why an actor bothers to interact with it.

A use case is not a specification, and does not replace ordinary design. We have had experiences with customers who simply retitle their traditional procedural programming specifications as “use cases”. We hypothesize that this comes from an unwillingness to separate problem definition from solution definition. The consequence is a conflation of use case, technical background, design and programming specifications into gargantuan documents that defy the ability of programmers or users to comprehend them.

There are a number of common problems with use cases that will make the design job more difficult. Each of these defects should lead to review of the use case with the authors to see what, if anything, they can do to rework the use case to be more complete.

- **No Actor.** Without an actor, it's impossible to tell who is getting value from the interaction. A catch-all title like “the user” indicates a use case written from the point of view of the database or the application software, not an actual person. An actor can be an interface with other software, in which case, the actual software needs to be named. Without knowing the actor, you will have trouble deciding which classes are clients and which classes provide the lower-level services of the application.

- **No Value Proposition.** There are two basic kinds of value: information for decision-making or actions taken as the result of decision-making. People interact with software because there are decisions the software cannot make or there are actions the actor cannot make. Some use cases include value-less activities like logging in, or committing a transaction, or clicking “Okay” to continue. These are parts of operating *scenarios*, not statements of value that show how the actor is happier or more successful. Without a value proposition, you will have no clue as to what problem the software solves, or what it eventually does for the actor.

- **No Interactions.** If the entire body of the use case is a series of steps the application performs, we are suspicious of the focus. We prefer a use case to emphasize interaction with the actor. Complex algorithms or interface specifications should be part of an appendix or supplemental document. Without any interaction, it isn't clear how the actor uses the software.

We also try to make a distinction between detailed operating scenarios and use cases. We have seen customers write documents they call “detailed use cases” that describe the behavior of individual graphical user interface widgets or panels. We prefer to call these scenarios, since they don't describe measuable business value, but instead describe technical interactions.

This system use case is embedded in an overall cycle of investigation that forms a kind of business use case. From this overall view, the actor's goal is to find an optimal strategy for a given game. The procedure includes the following steps.

**Procedure 1.2. Business Use Case**

1. **Actor**

   Researches alternative strategies. Uses IDE to build new classes.

2. **IDE**

   Creates new classes for the simulator.

3. **Actor**

   Uses the Basic Use Case. Runs the simulator with selection of game and strategy.

4. **Simulator**

   Responds with statistical results.

5. **Actor**

   Evaluates the results. Uses a spreadsheet or other tool for analysis and visualization.

We are addressing parts of this larger business use case. While not describing the detailed “how-to” of using the IDE to build the new classes, we will address the design of those new classes. Additionally, we won't address how to analyze the results.

## Solution Approach

From reading the problem and use case information, we can identify at least the following four general elements to our application.

- The game being simulated. This includes the various elements of the game: the wheel, the dice, the cards, the table and the bets.
- The player being simulated. This includes the various decisions the player makes based on the state of the game, and the various rules of the betting system the player is following.
- The statistics being collected.
- An overall control component which processes the game, collects the statistics and writes the details or the final summary.

When we look at common design patterns, the **Model-View-Control** pattern often helps to structure applications. A more sophisticated, transactional application may require a more complex structure. However, in this case, the game, the player, and the statistics are the model. The command line selection of player and the reporting of raw data is the view. The overall control component creates the various objects to start the simulation.

While interesting, we will not pursue the design of a general-purpose simulation framework. Nor will we use any of the available general frameworks. While these are handy and powerful tools, we want to focus on developing application software “from scratch” as a learning exercise.

Our solution will depend heavily on desktop integration: the actor will use their IDE to create a strategy and build a new version of the application program. Once the application is built, the actor can run the application from the command line, collecting the output file. The statistical results file can be analyzed using a spreadsheet application. There are at least three separate application programs involved: the IDE (including editor and compiler), the simulator, the spreadsheet used for analysis.

A typical execution of the simulator will look like the following example.

**Example 1.1. Sample Java Execution**

```
java ❶ casino.MainCrapsSim ❷ --Dplayer.name="Player1326" ❸ >details.log
```

❶ We select the main simulator control using the package `casino` and the class `MainCrapsSim`.

❷ We define the player to use `Player1326`. The main method will use this parameter to create objects and execute the simulation.

❸ We collect the raw data in a file named `details.log`.

We are intentionally limiting our approach to a simple command-line application using the default language libraries. Avoiding additional libraries assures a “lowest-common denominator” multi-platform application. For Java, this standard is the J2SE set of libraries; we won't use any J2EE extensions. For Python, it is the base installation.

There are a number of more technical considerations that we will expand in the section called “Deliverables”. These include the use of an overall simulation framework and an approach for unit testing.

Among the topics this book deals with in a casual -- possibly misleading -- manner are probability and statitics. Experts will spot a number of gaps in our exposition. For example, there isn't a compelling need for simulation of the simpler games of Craps and Roulette, since they can be completely analyzed. However, our primary objective is to study programming, not casino games, therefore we don't mind solving known problems again. We are aware that our statistical analysis has a number of deficiencies. We will avoid any deeper investigation into statistics.

## Methodology, Technique and Process

We want to focus on technical skills; we won't follow any particular software development methodology too closely. We hesitate to endorse a specific methodology; doing so inevitably alienates readers who embrace a different methodology. To continue this rant, we find that almost everyone has an existing notion of the proper way to organize software development work. This leads to the common practice of customizing methodologies, in most cases without a deep background in the methodology or the changes being made.

We prefer to lift up a few techniques which have a great deal of benefit.

- Incremental Development. Each chapter is a "sprint" that produces some collection of deliverables. Each part is a complete release.

- Unit Testing. We don't dwell on test-driven development, but each chapter explicitly requires unit tests for the classes built.

- Embedded Documentation. We provide appendices on how to use Epydoc or javadoc to create usable API documents.

The exercises are presented as if we are doing a kind of iterative design with very, very small deliverables. We present the exercises like this for a number of reasons.

First, we find that beginning designers work best with immediate feedback on their design decisions. While we present the design in considerable detail, we do not present the final code. Programmers new to OO design will benefit from repeated exposure to the transformation of problem statement through design to code.

Second, for iterative or agile methodologies, this presentation parallels the way software is developed. A project manager may use larger collections of deliverables. However, the actual creation of functional source eventually decomposes into classes, fields and methods. For project managers, this exposition will help them see where and how rework can occur; giving them a chance to plan for the kind of learning that occur in most projects.

Third, for project teams using a strict waterfall methodology -- with all design work completed before any programming work -- the book can be read in a slightly different order. From each exercise chapter, read only the overview and design sections. From that information, integrate the complete design. Then proceed through the deliverables sections of each chapter, removing duplicates and building only the final form of the deliverables based on the complete design. This will show how design rework arises as part of a waterfall methodology.

We try to embrace a variety of deliverables in addition to working source code. In particular, we expect unit test classes in addition to the functional classes. Further, we expect Javadoc comments or Python docstrings in each class. Additionally, we will need to write some demonstration classes in order to determine the exact sequence of random numbers that are created from a specific seed; these are not deliverable as part of the final application, but will be necessary to construct proper unit tests.

This section addresses a number of methodology or process topics:

- Quality, in general
- Rework
- Technical Decision-Making
- Reuse
- Design Patterns

## On Quality

Our approach to overall quality assurance is relatively simple. We feel that a focus on unit testing and documetation covers most of the generally accepted quality factors. The Software Engineering Institute (SEI) published a quality measures taxonomy. While officially "legacy", it still provides an exhaustive list of quality attributes. These are broadly grouped into five categories. Our approach covers most of those five categories reasonably well.

- **Need Satisfaction.** Does the software meet the need? We start with a problem statement, define the use case, and then write software which is narrowly focused on the actor's needs. By developing our application in small increments, we can ask ourself at each step, "Does this meet the actor's needs?" It's fairly easy to keep a software development project focused when we have use cases to describe our goals.
- **Performance.** We don't address this specifically in this book. However, the presence of extensive unit tests allows us to alter the implemention of classes to change the overall performance of our application. As long as the resulting class still passes the unit tests, we can develop numerous alternative implementations to optimize speed, memory use, input/output, or any other resource.
- **Maintenance.** Software is something that is frequently changed. It changes when we uncover bugs. More commonly, it changes when our understanding of the problem, the actor or the use case changes. In many cases, our initial solution merely clarifies the actor's thinking, and we have to alter the software to reflect a deeper understanding of the problem.

  Maintenance is just another cycle of the iterative approach we've chosen in this book. We pick a feature, create or modify classes, and then create or modify the unit tests. In the case of bug fixing, we often add unit tests to demonstrate the bug, and then fix our classes to pass the revised unit tests.
- **Adaptation.** Adaptation refers to our need to adapt our software to changes in the environment. The environment includes interfaces, the operating system or platform, even the number of users is part of the environment. When we address issues of interoperability with other software, portability to new operating systems, scalability for more users, we are addressing adaptation issues.

  We chose Python and Java to avoid having interoperability and portability issues — these platforms give admirable support for many scalability issues. Generally, a well-written piece of software can be reused. While this book doesn't focus on reuse, Java and Python are biased toward writing reusable software.
- **Organizational.** There are some organizational quality factors: cost of ownership and productivity of the developers creating it. We don't address these directly. Our approach, however, of developing software incrementally often leads to good developer productivity.

Our approach (Incremental, Unit Testing, Embedded Documentation) assures high quality in four of the five quality areas. Incremental development is a way to focus on need satisfaction. Unit testing helps us optimize resource use, and do maintenance well. Our choices of tools and platforms help us address adaptation.

The organizational impact of these techniques isn't so clear. It is easy to mis-manage a team and turn incremental development into a quagmire of too much planning for too little delivered software. It is all too common to declare that the effort spent writing unit test code is "wasted".

Ultimately, this is a book on OO design. How people organize themselves to build software is beyond our scope.

## On Rework

In the section called "Problem Statement", we described the problem. In the section called "Solution Approach", we provided an overview of the solution. The following parts will guide you through an incremental design process; a process that involves learning and exploring. This means that we will coach you to build classes and then modify those classes based on lessons learned during later steps in the design process. See our Soapbox on Rework for an opinion on the absolute necessity for design rework.

We don't simply present a completed design. We feel that it is very important follow a realistic problem-solving trajectory so that beginning designers are exposed to the decisions involved in creating a complete design. In our experience, all problems involve a considerable amount of "learn as you go". We want to reflect this in our series of exercises. In many respects, a successful OO design is one that respects the degrees of ignorance that people have when starting to build software. We will try to present the exercises in a way that teaches the reader how to manage ignorance and still develop valuable software.

**Soapbox on Rework**

We consider design rework to be so important, we will summarize the idea here.

## Important

The best way to learn is to make mistakes.

Rework is a consequence of learning.

All of software development can be described as various forms of knowledge capture. A project begins with many kinds of ignorance and takes steps to reduce that ignorance. Some of those steps should involve revising or consolidating previous learnings.

A project without rework is suspiciously under-engineered.

For some, the word *rework* has a negative connotation. If you find the word distasteful, please replace every occurance with any of the synonyms: adaptation, evolution, enhancement, mutation. We prefer the slightly negative connotation of the word rework because it helps managers realize the importance of incremental learning and how it changes the requirements, the design and the resulting software.

Since learning will involve mistakes, good management plans for the costs and risks of those mistakes. Generally, our approach is to manage our ignorance; we try to create a design such that correcting a mistake only fixes a few classes.

We often observe denial of the amount of ignorance involved in creating IT solutions. It is sometimes very difficult to make it clear that if the problem was well-understood, or the solution was well-defined there would be immediately applicable off-the-shelf or open-source solutions. The absence of a ready-to-hand solution generally means the problem is hard. It also means that there are several degrees of ignorance: ignorance of the problem, solution and technology; not to mention ignorance of the amount of ignorance involved in each of these areas.

We see a number of consequences of denying the degrees of ignorance.

**Programmers.** For programmers, experienced in non-OO (e.g. *procedural*) environments, one consequnece is that they find learning OO design is difficult and frustrating. Our advice is that since this is new, you have to make mistakes or you won't learn effectively. Allow yourself to explore and make mistakes; feel free to rework your solutions to make them better. Above all, do not attempt to design a solution that is complete and perfect the very first time. We can't emphasize enough the need to do design many times before understanding what is important and what is not important in coping with ignorance.

In one advanced programming course, we observed the following sad scenario. The instructor provided an excellent background in how to create abstract data type (ADT) definitions for the purely mathematical objects of *scalar*, *vector* and *matrix*. The idea was to leverage the ADTs to implement more complex operations like matrix multiplication, inversion and Gaussian elimination. The audience, primarily engineers, seemed to understand how this applied to things they did every day. The first solution, presented after a week of work, began with the following statement: “Rather than think it through from the basic definitions of matrix and vector, I looked around in my drawer and found an old FORTRAN program and rewrote that, basically transliterating the FORTRAN.” We think that a lack of experience in the process of software design makes it seem that copying an inappropriate solution is more effective than designing a good solution from scratch.

**Managers.** For managers, experienced in non-object implementation, the design rework appears to be contrary to a fanciful expectation of reduced development effort from OO techniques. The usual form for the complaint is the following: “I thought that OO design was supposed to be easier than non-OO design.” We're not sure where the expectation originates, but good design takes time, and learning to do good design seems to require making mistakes. Every project needs a budget for making the necessary mistakes, reworking bad ideas to make them good and searching for simplifications.

**Methodology.** Often, management attempts the false economy of minimizing rework by resorting to a *waterfall* methodology. The idea is that having the design complete before attempting to do any development prevents design rework. We don't see that this waterfall approach minimizes rework; rather, we see it shifting the rework forward in the process. There are two issues ignored by this approach: how we grow to understand the problem domain and providing an appropriate level of design detail.

We find that the initial “high-level” design can miss details of the problem domain, and this leads to rework. Forbidding rework amounts to mandating a full understanding of the problem. In most cases, our users do not fully understand their problem any more than our developers understand our users. Generally, it is very hard to understand the problem, or the solution. We find that hands-on use of preliminary versions of software can help more than endless conversations about what could be built.

In the programming arena, we find that Java and Python (and their associated libraries) are so powerful that detailed design is done at the level of individual language statements. This leads us to write the program either in English prose or UML diagrams (sometimes both) before writing the program in the final programming language. We often develop a strong commitment to the initial design, and subsequent revisions are merely transliterations with no time permitted for substantial revisions. While we have written the program two or three times over, the additional quality isn't worth doubling or tripling the workload. We feel that the original workload should be managed as planned cycles of work and rework.

## On Decision-Making

Many of the chapters will include some lengthy design decisions that appear to be little more than handwringning over nuances. While this is true to an extent, we need to emphasize our technique for doing appropriate hand-wringing over OO design. We call it “Looking For The Big Simple”, and find that managers don't often permit the careful enumeration of all the alternatives and the itemization of the pros and cons of each choice. We have worked with managers who capriciously play their “schedule” or “budget” trump cards, stopping useful discussion of alternatives. This may stem from a fundamental discomfort with the technology, and a consequent discomfort of appearing lost in front of team members and direct reports. Our suggestion in this book can be summarized as follows:

### Important

Good OO design comes from a good process for technical decision-making.

First, admit what we don't know, and then take steps to reduce our degrees of ignorance.

Which means not saying “work smarter not harder” unless we also provide the time and budget to actually get smarter. The learning process, as with all things, must be planned and managed. Our lesson learned from Blaise Pascal is that a little more time spent on design can result in considerable simplification, which will reduce development and maintenance costs.

It's also important to note that no one in the real world is omniscient. Some of the exercises include intentional dead-ends. As a practical matter, we can rarely foresee all of the consequences of a design decision.

## On Reuse

While there is a great deal of commonality among the three games, the exercises do not start with an emphasis on constructing a general framework. We find that too much generalization and too much emphasis on *reuse* is not appropriate for beginning object designers. See Soapbox on Reuse for an opinion on reuse. Additionally, we find that projects that begin with too-lofty reuse goals often fail to deliver valuable solutions in a timely fashion. We prefer not to start out with a goal that amounts to boiling the ocean to make a pot of tea.

### Soapbox on Reuse

While a promise of OO design is reuse, this needs to be tempered with some pragmatic considerations. There are two important areas of reuse: reusing a class specification to create objects with common structure and behavior, and using inheritance to reuse structure and behavior among multiple classes of objects. Beyond these two areas, reuse can create more cost than value.

The first step in reuse comes from isolating responsibilities to create classes of objects. Generally, a number of objects that have common structure and behavior is a kind of reuse. When these objects cooperate to achieve the desired results, this is sometimes called *emergent behavior*: no single class contains the overall functionality, it grew from the interactions among the various objects.

When the application grows and evolves, we can preserve some class declarations, reusing them in the next revision of the application. This reduces the cost and risks associated with software change. Class definitions are the most fundamental and valuable kind of reuse.

Another vehicle for OO resuse is inheritance. The simple subclass-superclass relationship yields a form of reuse; a class hierarchy with six subclasses will share the superclass code seven times over. This, by itself, has tremendous benefits.

We caution against any larger scope of reuse. Sharing classes between projects may or may not work out well. The complexity of achieving inter-project reuse can be paralyzing to first-time designers. Often, different projects reflect different points of view, and the amount of sharing is limited by these points of view. As an example, consider a product in a business context. An external customer's view of the product (shaped by sales and marketing) may be very different from the internal views of the same product. Internal views of the product (for example, finance, legal, manufacturing, shipping, support) may be very different from each other. Reconciling these views may be far more challenging than a single software development project. For that reason, we don't encourage this broader view of reuse.

### On Design Patterns

These exercises will refer to several of the “Gang of Four” design patterns in Gamma95. The Design Patterns book is not a prerequisite; we use it as reference material to provide additional insight into the design patterns used here. We feel that use of common design patterns significantly expands the programmer's repertoire of techniques. We note where they are appropriate, and provide some guidance in their implementation.

In addition, we reference several other design patterns which are not as well documented. These are, in some cases, patterns of bad design more than patterns of good design.

## Deliverables

Each chapter defines the classes to be built and the unit testing that is expected. A third deliverable is merely implied. The purpose of each chapter is to write the source files for one or more classes, the source files for one or more unit tests, and assure that a minimal set of API documentation is available.

**Source Files.** The source files are the most important deliverable. In effect, this is the working application program. Generally, you will be running this application from within your Integrated Development Environment (IDE). You may want to create a stand-alone program.

In the case of Java, we might also deliver the collection of class files. Additionally, we might bundle the class files into an executable JAR file. The source is the principle deliverable; anyone should be able to produce class and JAR files using readily available tools.

In the case of Python, it's the packages of `.py` files. There really isn't much more to deliver. The interested student might want to look at the Python `distutils` and `setuptools` to create a distribution kit, or possibly a Python `egg` file.

**Unit Test Files.** The deliverables section of each chapter summarizes the unit testing that is expected, in addition to the classes to be built. We feel that unit testing is a critical skill, and emphasize it throughout the inividual exercises. We don't endorse a particular technology for implementing the unit tests. There are several approaches to unit testing that are in common use.

- **Formal Unit Tests.** For formal testing of some class, `X`, we create a separate class, `TestX`, which creates instances of `X` and exercises those instances to be sure they work. In Java, this is often done with `JUnit`. In Python, the `unittest` module is the mechanism for doing formal unit tests. Additionally, many Python developers also use the `doctest` module to assure that the sample code in the docstrings is actually correct. We cover these technologies in the appendices.
- **Informal Unit Tests.** This is often done by include a main program in the class definition file. We'll show two examples of this. By following the standard unit test naming conventions, these informal tests can be easily upgraded to more formal JUnit or PyUnit tests.

In Python, an informal is done by including the following block of code section in a module file. Each test method must have a name that starts with “test” to be compatible with the Python `PyUnit` module.

**Example 1.2. Informal Python Unit Test**

```
def testX():
    test procedure X goes here
def testY():
    test procedure Y goes here

if __name__ == "__main__":
    testX()
    testY()
```

In Java, this is done by putting `public static void main(String[] args);` in the class source file. Each test method must have a name that starts with “test” to be compatible with the Java `JUnit` package.

**Example 1.3. Informal Java Unit Test**

```
class SomeClass {

    public static void main( String[] args ) {
        SomeClass x= new SomeClass();
        x.testX();
        x.testY();
    }

    public void testX() {
        test procedure X goes here
    }
    public void testY() {
        test procedure Y goes here
    }

}
```

**Documentation.** The job isn't over until the paperwork is done. In the case of Java and Python, the internal documentation is generally built from specially formatted blocks of comments within the source itself. Java programmers can use the javadoc tool to create documentation from the program source. Python programmers can use Epydoc to create similar documentation.

# Roulette

This part describes the game of Roulette. Roulette is a stateless game with numerous bets and a very simple process for game play.

The chapters of this part present the details on the game, an overview of the solution, and a series of sixteen exercises to build a complete simulation of the game, plus a variety of betting strategies. Each exercise chapter builds at least one class, plus unit tests; in some cases, this includes rework of previous deliverables.

**Table of Contents**

# Chapter 2. Roulette Details

**Table of Contents**

In the first section we will present a summary of the game of Roulette as played in most American casinos.

We will follow this with a review the various bets available on the Roulette table in some depth. The definition of the various bets is an interesting programming exercise, and the first four exercise chapters will focus on this.

Finally, we will describe some common betting strategies that we will simulate. The betting strategies are interesting and moderately complex algorithms for changing the amount that is used for each bet in an attempt to recoup losses.

## Roulette Game

The game of Roulette centers around a *wheel* with thirty-eight numbered *bins*. The numbers include 0, 00 (double zero), 1 through 36. The *table* has a surface marked with spaces on which players can place *bets*. The spaces include the 38 *numbers*, plus a variety of additional bets, which will be detailed below. After the bets are placed by the players, the wheel is spun by the house, a small ball is dropped into the spinning wheel; when the wheel stops spinning, the ball will come to rest in one of the thirty-eight numbered bins, defining the winning number. The winning number and all of the related winning bets are paid off; the losing bets are collected. Roulette bets are all paid off using *odds*, which will be detailed with each of the bets, below.

The numbers from 1 to 36 are colored red and black in an arbitrary pattern. They fit into various ranges, as well as being even or odd, which defines many of the winning bets related to a given number. The numbers 0 and 00 are colored green, they fit into none of the ranges, and are considered to be neither even nor odd. There are relatively few bets related to the zeroes. The geometry of the betting locations on the table defines the relationships between number bets.

### Note

There are slight variations in Roulette between American and European casinos. We'll focus strictly on the American version.

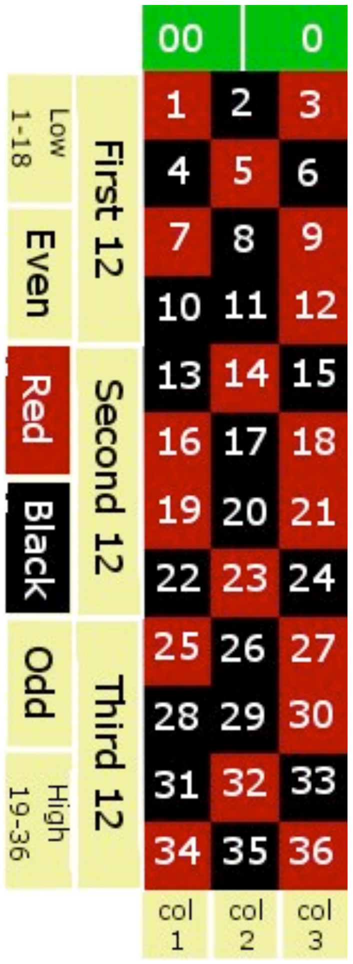
## Available Bets

There are a variety of bets available on the Roulette table. Each bet has a payout, which is stated as *n*:1 where *n* is the multiplier that defines the amount won based on the amount bet.

A $5 bet at 2:1 will win $10. After you are paid, there will be $15 sitting on the table, your original $5 bet, plus your $10 additional winnings.

### Note

Not all games state their odds using this convention. Some games state the odds as “2 *for* 1”. This means that the total left on the table after the bets are paid will be two times the original bet. So a $5 bet will win $5, there will be $10 sitting on the table.



Roulette Table Layout

The table is divided into two classes of bets. The “inside” bets are the 38 numbers and small groups of numbers; these bets all have relatively high odds. The “outside” bets are large groups of numbers, and have relatively low odds. If you are new to casino gambling, see Odds and Payouts for more information on odds and why they are offered.

- A “straight bet” is a bet on a single number. There are 38 possible bets, and they pay odds of 35 to 1. Each bin on the wheel pays one of the straight bets.
- A “split bet” is a bet on an adjacent pair of numbers. It pays 17:1. The table layout has the numbers arranged sequentially in three columns and twelve rows. Adjacent numbers are in the same row or column. The number 5 is adjacent to 4, 6, 2, 8; the number 1 is adjacent to 2 and 4. There are 114 of these split bet combinations. Each bin on the wheel pays from two to four of the available split bets. Any of two bins can make a split bet a winner.
- A “street bet” includes the three numbers in a single row, which pays 11:1. There are twelve of these bets on the table. A single bin selects one street bet; any of three bins make a street bet a winner.
- A square of four numbers is called a “corner bet” and pays 8:1. There are 72 of these bets available.
- At one end of the layout, it is possible to place a bet on the Five numbers 0, 00, 1, 2 and 3. This pays 6:1. It is the only combination bet that includes 0 or 00.
- A “line bet” is a six number block, which pays 5:1. It is essentially two adjacent street bets. There are 11 such combinations.

The following bets are the “outside” bets. Each of these involves a group of twelve to eighteen related numbers. None of these outside bets includes 0 or 00. The only way to bet on 0 or 00 is to place a straight bet on the number itself, or use the five-number combination bet.

- Any of the three 12-number ranges (1-12, 13-24, 25-36) pays 2:1. There are just three of these bets.
- The layout offers the three 12-number columns at 2:1 odds. All of the numbers in a given column have the same remainder when divided by three. Column 1 contains 1, 4, 7, etc., all of which have a remainder of 1 when divided by 3.
- There are two 18-number ranges: 1-18 is called *low*, 19-36 is called *high*. These are called even money bets because they pay at 1:1 odds.
- The individual numbers are colored red or black in an arbitrary pattern. Note that 0 and 00 are colored green. The bets on red or black are even money bets, which pay at 1:1 odds.
- The numbers (other than 0 and 00) are also either even or odd. These bets are also even money bets.

### Odds and Payouts

Not all of the Roulette outcomes are equal probability. Let's compare a “split bet” on 1-2 and a *even money* bet on red.

- The split bet wins if either 1 or 2 comes up on the wheel. This is 2 of the 38 outcomes, or a 1/19 probability, 5.26%.
- The red bet wins if any of the 18 red numbers come up on the wheel. The is 18 of the 38 outcomes, or a 9/19 probability, 47.4%.

Clearly, the red bet is going to win almost ten times more often than the 1-2 bet. As an inducement to place bets on rare occurences, the house offers a higher payout on those bets. Since the 1-2 split bet wins is so rarely, they will pay you 17 times what you bet. On the other hand, since the red bet wins so frequently, they will only pay back what you bet.

You'll notice that the odds of winning the 1-2 split bet is 1 chance in 19, but they pay you 17 times your bet. Since your bet is still sitting on the table, it looks like 18 times your bet. It still isn't 19 times your bet. This discrepency between the actual probability and the payout odds is sometimes called the *house edge*. It varies widely among the various bets in the game of Roulette. For example, the 5-way bet has 5/38 ways of winning, but pays only 6:1. There is only a 13.2% chance of winning, but they pay you as if you had a 16.7% chance, keeping the 3.5% difference. You have a 5.26% chance to win a split bet, but the house pays as if it were a 5.88% chance, a .62% discrepency in the odds.

The smallest discrepency between actual chances of winning (47.4%) and the payout odds (50%) is available on the even money bets: red, black, even, odd, high or low. All the betting systems that we will look at focus on these bets alone, since the house edge is the smallest.

## Some Betting Strategies

Perhaps because Roulette is a relatively simple game, elaborate betting systems have evolved around it. Searches on the Internet turn up a many copies of the same basic descriptions for a number of betting systems. Our purpose is not to uncover the actual history of these systems, but to exploit them for simple

OO design exercises. Feel free to research additional betting systems or invent your own.

The *Martingale* system starts with a base wagering amount, *w*, and a count of the number of losses, *c*, initially 0. Each loss doubles the bet; any given spin will place an amount of $w*2^c$ on a 1:1 proposition (for example, red). When a bet wins, the loss count is reset to zero; resetting the bet to the base amount, *w*. This assures that a single win will recoup all losses.

Note that the casinos effectively prevent successful use of this system by imposing a table limit. At a $10 Roulette table, the limit may be as low as $1,000. A Martingale bettor who lost six times in a row would be facing a $640 bet, and after the seventh loss, their next bet would exceed the table limit. At that point, the player is unable to recoup all of their losses. Seven losses in a row is only a 1 in 128 probability; making this a relatively likely situation.

Another system is to wait until some number of losses have elapsed. For example, wait until the wheel has spun seven reds in a row, and then bet on black. This can be combined with the Martingale system to double the bet on each loss as well as waiting for seven reds before betting on black.

Another betting system is called the *1-3-2-6* system. The idea is to avoid the doubling of the bet at each loss and running into the table limit. Rather than attempt to recoup all losses in a single win, this system looks to recoup all losses by waiting for four wins in a row. The sequence of numbers (1, 3, 2 and 6) are the multipliers to use when placing bets after winning. At each loss, the sequence resets to the multiplier of 1. At each win, the multiplier is advanced through the sequence. After one win, the bet is now 3*w*. After a second win, the bet is reduced to 2*w*, and the winnings of 4*w* are “taken down” or removed from play. In the event of a third win, the bet is advanced to 6*w*. Should there be a fourth win, the player has doubled their money, and the sequence resets.

Another method for tracking the lost bets is called the *Cancellation* system or the *Labouchere* system. The player starts with a betting budget allocated as a series of numbers. The usual example is 1, 2, 3, 4, 5, 6, 7, 8, 9. Each bet is sum of the first and last numbers in the last. In this case 1+9 is 10. At a win, cancel the two numbers used to make the bet. In the event of all the numbers being cancelled, reset the sequence of numbers and start again. For each loss, however, add the amount of the bet to the end of the sequence as a loss to be recouped.

Here's an example of the cancellation system using 1, 2, 3, 4, 5, 6, 7, 8, 9.

1. Bet 1+9. A win. Cancel 1 and 9 leaving 2, 3, 4, 5, 6, 7, 8.
2. Bet 2+8. A loss. Add 10 leaving 2, 3, 4, 5, 6, 7, 8, 10.
3. Bet 2+10. A loss. Add 12 leaving 2, 3, 4, 5, 6, 7, 8, 10, 12.
4. Bet 2+12. A win. Cancel 2 and 12 leaving 3, 4, 5, 6, 7, 8, 10.
5. Next bet will be 3+10.

A player could use the *Fibonacci Sequence* to structure a series of bets in a kind of cancellation system. The Fibonacci Sequence is 1, 1, 2, 3, 5, 8, 13, .... At each loss, the sum of the previous two bets -- the next number in the sequence -- becomes the new bet amount. In the event of a win, the last two numbers in the sequence are removed. This allows the player to easily track our accumulated losses, with bets that could recoup those losses through a series of wins.

# Chapter 3. Roulette Solution Overview

**Table of Contents**

The first section is a survey of the classes gleaned from the general problem statement in Problem Statement as well as the problem details in Roulette Details. This survey is drawn from a quick overview of the key nouns in these sections.

Given this survey of the candidate classes, the second section is a walkthrough of the possible design that will refine the definitions, and give us some assurance that we have a reasonable architecture. We will make some changes to the preliminary class list, revising and expanding on our survey.

We will also include a number of questions and answers about this preliminary design information. This should help clarify the design presentation and set the stage for the various development exercises in the chapters that follow.

## Preliminary Survey of Classes

To provide a starting point for the development effort, we have to identify the objects and define their responsibilities. The central principle behind the allocation of responsibility is *encapsulation*; we do this by attempting to *isolate the information* or *isolate the processing* that must be done. Encapsulation assures that the methods of a class are the exclusive users of the fields of that class. It also makes each class very loosely coupled with other classes; this permits change without a ripple through the application. For example, each `Outcome` contains both the name and the payout odds. That way each `Outcome` can be used to compute a winning amount, and no other element of the simulation needs to share the odds information or the payout calculation.

In a few cases, we have looked forward to anticipate some future considerations. One such consideration is the house *"rake"*, also known as the *"vigorish"*, *"vig"*, or *commission*. In some games, the house makes a 5% deduction from some payouts. This complexity is best isolated in the `Outcome` class. Roulette doesn't have any need for a rake, since the presence of the 0 and 00 on the wheel gives the house a little over 5% edge on each bet. We'll design our class so that this can be added later when we implement Craps.

In reading the background information and the problem statement, we noticed a number of nouns that seemed to be important parts of the game we are simulating.

Wheel
Bet
Bin

Table
Red
Black
Green
Number
Odds
Player
House

One common development milestone is to be able to develop a class model in the Unified Modeling Language (UML) to describe the relationships among the various nouns in the problem statement. Building (and interpreting) this model takes some experience with OO programming. In this first part, we'll avoid doing extensive modeling. Instead we'll simply identify some basic design principles. We'll focus in on the most important of these nouns and describe the kinds of classes that you will build.

The following table summarizes some of the classes and responsibilities that we can identify from the problem statement. This is not the complete list of classes we need to build. As we work through the exercises, we'll discover additional classes and rework some of these preliminary classes more than once.

**Preliminary Roulette Class Structure**

| Class | Responsibilities | Collaborations |
|---|---|---|
| `Outcome` | A name for the bet and the payout odds. This isolates the calculation of the payout amount. Example: "Red", "1:1". | Collected by `Wheel` into the bins that reflect the bets that win; collected by `Table` into the available bets for the `Player`; used by `Game` to compute the amount won from the amount that was bet. |
| `Wheel` | Selects the `Outcomes` that win. This isolates the use of a random number generator to select `Outcomes`; and it encapsulates the set of winning `Outcomes` that are associated with each individual number on the wheel. Example: the "1" bin has the following winning `Outcomes`: "1", "Red", "Odd", "Low", "Column 1", "Dozen 1-12", "Split 1-2", "Split 1-4", "Street 1-2-3", "Corner 1-2-4-5", "Five Bet", "Line 1-2-3-4-5-6", "00-0-1-2-3", "Dozen 1", "Low" and "Column 1". | Collects the `Outcomes` into bins; used by the overall `Game` to get a next set of winning `Outcomes`. |
| `Table` | A collection of bets placed on `Outcomes` by a `Player`. This isolates the set of possible bets and the management of the amounts currently at risk on each bet. This also serves as the interface between the `Player` and the other elements of the game. | Collects the `Outcomes`; used by `Player` to place a bet amount on a specific `Outcome`; used by `Game` to compute the amount won from the amount that was bet. |
| | | Uses `Table` to place bets on |

| | | |
|---|---|---|
| `Player` | Places bets on `Outcomes`, updates the stake with amounts won and lost. | Uses `Table` to place bets on `Outcomes`; used by `Game` to record wins and losses. |
| `Game` | Runs the game: gets bets from `Player`, spins `Wheel`, collects losing bets, pays winning bets. This encapsulates the basic sequence of play into a single class. | Uses `Wheel`, `Table`, `Outcome`, `Player`. The overall statistical analysis will play a finite number of games and collect the final value of the `Player`'s stake. |

The class `Player` has the most important responsibility in the application, since we expect to update the algorithms this class uses to place different kinds of bets. Clearly, we need to cleanly encapsulate the `Player`, so that changes to this class have no ripple effect in other classes of the application.

## A Walkthrough of Roulette

A good preliminary task is to review these responsibilities to confirm that a complete cycle of play is possible. This will help provide some design details for each class. It will also provide some insight into classes that may be missing from this overview.

A good way to structure this task is to do a Class-Reponsibility-Collaborators (CRC) *walkthrough*. As preparation, get some 5" x 8" notecards. On each card, write down the name of a class, the responsibilities and the collaborators. Leave plenty of room around the responsibilities and collaborators to write notes. We've only identified five classes, so far, but others always show up during the walkthrough.

During the walkthrough, we identify areas of responsibility, allocate them to classes of objects and define any collaborating objects. An area of responsibility is a thing to do, a piece of information, a result. Sometimes a big piece of responsibility can be broken down into smaller pieces, and those smaller pieces assigned to other classes. There are a lot of reasons for decomposing, the purpose of this book is to explore many of them in depth. Therefore, we won't justify any of our suggestions until later in the book. For now, follow along closely to get a sense of where the exercises will be leading.

The basic processing outline is the responsibility of the `Game` class. To start, locate the `Game` card.

1. Our preliminary note was that this class “Runs the game.” The responsibilities section has a summary of four steps involved in running the game.

2. The first step is “gets bets from `Player`.” Find the `Player` card.

3. Does a `Player` collaborate with a `Game` to place bets? If not, update the cards as necessary to include this.

4. One of the responsibilities of a `Player` is to place bets. The step in the responsibility statement is merely “Places bets on `Outcomes`.” Looking at the classes, we note that the `Table` contains the amounts placed on the Bets. Fix the collaboration information on the `Player` to name the `Table` class. Find the `Table` card.

5. Does a `Table` collaborate with a `Player` to accept the bets? If not, update the cards as necessary to

include this.

6. What card has responsibility for the amount of the bet? It looks like `Table`. We note one small problem: the `Table` contains the *collection* of amounts bet on `Outcomes`. What class contains the individual “amount bet on an `Outcome`?” This class appears to be missing. We'll call this new class `Bet` and start a new card. We know one responsibility is to hold the amount bet on a particular `Outcome`. We know three collaborators: the amount is paired with an `Outcome`, all of the `Bets` are collected by a `Table`, and the `Bets` are created by a `Player`. We'll update all of the existing cards to name their collaboration with `Bet`.

7. What card has responsibility for keeping all of the `Bets`? Does `Table` list that as a responsibility? We should update these cards to clarify this collaboration.

You should continue this tour, working your way through spinning the `Wheel` to get a list of winning `Outcomes`. From there, the `Game` can get all of the `Bets` from the `Table` and see which are based on winning `Outcomes` and which are based on losing `Outcomes`. The `Game` can notify the `Player` of each losing `Bet`, and notify the `Player` of each winning `Bet`, using the `Outcome` to compute the winning amount.

This walkthrough will give you an overview of some of the interactions among the objects in the working application. You may uncover additional design ideas from this walkthrough. The most important outcome of the walkthrough is a clear sense of the responsibilities and the collaborations required to create the necessary application behavior.

## Questions and Answers

**Q:** Why does the `Game` class run the sequence of steps? Isn't that the responsibility of some “main program?”

**A:** **Coffee Shop Answer.** We haven't finished designing the entire application, so we need to reflect our own ignorance of how the final application will be assembled from the various parts. Rather than allocate too many responsibilities to `Game`, and possibly finding conflicts or complication, we'd rather allocate too few responsibilities until we know more.

From another point of view, designing the main program is premature because we haven't finished designing the *entire* application. We anticipate a `Game` object being invoked from some statistical data gathering object to run one game. The data gathering object will then get the final stake from the player and record this. `Game`'s responsibilities are focused on playing the game itself. We'll need to add a responsibility to `Game` to collaborate with the data gathering class to run a number of games as a “session”.

**Deeper Answer.** In procedural programming (especially in languages like COBOL), the “main program" is allocated almost all of the responsibilities. These procedural main programs usually contain a number of elements, all of which are very tightly coupled. We have seen highly skilled programmers who are able to limit the amount of work done in the main program, even in procedural languages. In OO languages, it becomes possible for even moderately skilled programmers to reduce the main program to a short list of object constructors, with the real work delegated to the objects. We find that "main program" classes are relatively hard to reuse, and prefer to keep them as short as possible.

**Q:** Why is `Outcome` a separate class? Each object that is an instance of `Outcome` only has two attributes; why not use an array of Strings for the names, and a parallel array of integers for the odds?

**A:** **Representation.** We prefer not to decompose an object into separate data elements. If we do decompose this object, we will have to ask which class would own these two arrays? If `Wheel` keeps these, then `Table` becomes very tightly coupled to these two arrays that should be `Wheel`'s responsibility. If `Table` keeps these, then `Wheel` is priviledged to know details of how `Table` is implemented. If we need to change these arrays to another storage structure, two classes would change instead of one.

Having the name and odds in a single `Outcome` object allows us to change the representation of an `Outcome`. For example, we might replace the String as the identification of the outcome, with a collection of the individual numbers that comprise this outcome. This would identify a straight bet by the single winning number; an even money bet would be identified by an array of the 18 winning numbers.

**Responsibility.** he principle of isolating responsibility would be broken by this "two parallel arrays" design because now the `Game` class would need to know how to compute odds. In more complex games, there would be the added complication of figuring the rake. Consider a game where the `Player`'s strategy depends on the potential payout. Now the `Game` and the `Player` both have copies of the algorithm for computing the payout. A change to one must be paired with a change to the other.

The alternative we have chosen is to encapsulate the payout algorithm along with the relevant data items in a single bundle.

**Q:** If `Outcome` encapsulates the function to compute the amount won, isn't it just a glorified subroutine?

**A:** In a limited way, yes. A class can be thought of as a glorified *subroutine library* that captures and isolates data elements along with their associated functions. For some new designers, this is a helpful summary of the basic principle of encapsulation. Inheritance and subclasses, however, make a class more powerful than a simple subroutine library with private data. Inheritance is a way to create a family of closely-related subroutine libraries in a simple way that is validated by the compiler.

**Q:** What is the distinction between an `Outcome` and a `Bet`?

**A:** We need to describe the propositions on the table on which you can place bets. The propositions are distinct from an actual amount of money wagered on a proposition. There are a lot of terms to choose from, including bet, wager, proposition, place, location, or outcome. We opted for using `Outcome` because it seemed to express the open-ended nature of a potential outcome, different from an amount bet on a potential outcome. In a way, we're considering the `Outcome` as an abstract possibility, and the `Bet` as a concrete action taken by a player.

Also, as we expand this simulation to cover other games, we will find that the randomized outcome is not something we can directly bet on. In Roulette, however, all outcomes are something we can be bet on, as well as a great many combinations of outcomes. We will revisit this design decision as we move on to other games.

**Q:** Why are the classes so small?

**A:** First-time designers of OO applications are sometimes uncomfortable with the notion of *emergent behavior*. In procedural programming languages, the application's features are always embodied in a few key procedures. Sometimes a single procedure, named `main`.

A good OO design partitions responsibility. In many cases, this subdivision of the application's features means that the overall behavior is not captured in one central place. Rather, it emerges from the interactions of a number of objects.

We have found that smaller elements, with very finely divided responsibilities, are more flexible and permit change. If a change will only alter a portion of a large class, it can make that portion incompatible with other portions of the same class. A symptom of this is a bewildering nest of if-statements to sort out the various alternatives. When the design is decomposed down more finely, a change can be more easily isolated to a single class. A much simpler sequence of if-statements can be focused on selecting the proper class, which can then simply carry out the desired functions.

# Chapter 4. Outcome Class

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In addition to defining the fundamental `Outcome` on which all gambling is based, this chapter provides a sidebar discussion on the notion of object identity and object equality. This is important because we will be dealing with a number of individual `Outcome` objects, and we need to be sure we can test for *equality* of two different objects. This is different from the test for *identity* which asks if we have two references to the same object.

## Overview

The first class we will tackle is a small class that encapsulates each outcome. This class will contain the name of the outcome as a String, and the odds that are paid as an integer. We will use these objects when placing a bet and also when defining the Roulette wheel.

There will be several hundred instances of this class on a given Roulette table. The bins on the wheel, similarly, collect various `Outcomes` together. The minimum set of `Outcome` instances we will need are the 38 numbers, Red and Black. The other instances add details to our simulation.

In Roulette, the amount won is a simple multiplication of the amount bet and the odds. In other games, however, there may be a more complex calculation because the house keeps 5% of the winnings, called the "rake". While it is not part of Roulette, it is good to have our `Outcome` class designed to cope with these more complex payout rules.

Also, we know that other casino games, like Craps, are stateful. An `Outcome` may change the game state. We can foresee reworking this class to add in the necessary features to change the state of the game.

While we are also aware that some odds are not stated as *x*:1, we won't include these other kinds of odds in this initial design. Since all Roulette odds are *x*:1, we'll simply assume that the denominator is always 1. We can forsee reworking this class to handle more complex odds, but we don't need to handle the other cases yet.

## On Object Identity

Our design will depend on matching `Outcome` objects between the wheel and bets placed on the table. The wheel will select the winning `Outcomes`, the player will be placing bets on `Outcomes` and the table will be holding bets that contain `Outcomes`. We need a simple test to see if two `Outcomes` are the same.

Additionally, as we look forward, the Java `Set` and `Map` depend on the `hashCode` method and `equals` method of each object in the collection.

When we read the *Application Program Interface* (API) definitions, we see that the default test for equality between two objects is to simply compare the object's hashcodes. Further, an object's hashcode is simply a unique integer, perhaps the address of the object. This means that each distinct object will tend to have distinct hashcodes, even if the objects are otherwise indistinguishable.

This default behavior of objects is shown by the following example:

**Example 4.1. Object Identity**

```
Outcome oc1 = new Outcome( "Any Craps", 8, 1 ); ❶
System.out.println( "oc1 = " + oc1 );
Outcome oc2 = new Outcome( "Any Craps", 8, 1 ); ❷
System.out.println( "oc2 = " + oc2 );
System.out.println( "equal = " + (oc1 == oc2) );
```

❶ Here we create an instance of `Outcome`.

❷ Here we create a second instance of `Outcome`. Because we have not provided our own `equals` and `hashCode` methods, these two objects are distinct.

This fragment produced the following output.

```
oc1 = Outcome@7ced01
oc2 = Outcome@1ac04e8
equal = false
```

Each individual `Outcome` object has a distinct address, and a distinct hashcode. This makes them not equal according to the default methods inherited from `Object`. However, we would like to have two of these objects test as equal and hash to the same location in a `Map`.

We need to have these two `Outcome` objects compare as equal and have the same hashCode. This is accomplished by overiding inherited methods with class-specific processing. In this case, we'll need to do the following:

1. Provide a method for `equals` that compares the name of the `Outcome` instead of the hashcode.
2. Provide a method for `hashCode` that computes a hashcode based only on the name of the `Outcome` instead of the address of the object in memory. The `String` class has an `intern` method that looks up the given String in a private set of unique Strings and returns one of those private String objects. By using this set of Strings, we can be assured that two distinct instances of `Outcome` with the same name will also have the same hashcode and will compare as equal.

In Python, the names of the methods change, but the approach of defining an equality test as well as a hash code is the same. The __`hash`__ method should compute the integer hashcode of the `Outcome` instance. The __`eq`__ method and __`ne`__ method should also be defined to compare `Outcome` names.

Ordinarily, instances of a class are considered mutable in Python, and unsuitable for keys to a dictionary or map. In this case, however, we have designed `Outcomes` to be immutable. By providing a method for __`hash`__ that uses the name of the `Outcome`, we provide an immutable hash function that gives the same hash value to all `Outcomes` with the same name.

## Design

`Outcome` contains a single outcome on which a bet can be placed. In Roulette, each spin of the wheel has a number of `Outcomes`. For example, the “1” bin has the following winning `Outcomes`: “1”, “Red”, “Odd”, “Low”, “Column 1”, “Dozen 1-12”, “Split 1-2”, “Split 1-4”, “Street 1-2-3”, “Corner 1-2-4-5”, “Five Bet”, “Line 1-2-3-4-5-6”, “00-0-1-2-3”, “Dozen 1”, “Low” and “Column 1”.

### Fields

- `String name ;`

  Holds the name of the `Outcome`. Examples include `"1"`, `"Red"`.

- `int odds ;`

  Holds the payout odds for this `Outcome`. Most odds are stated as 1:1 or 17:1, we only keep the numerator (17) and assume the denominator is 1.

### Constructors

- `Outcome(String name,
          int odds);`

  Sets the local name and odds from the parameter name and odds.

## Methods

- `int winAmount(int amount);`

  Multiplies this `Outcome`'s odds by the given amount. The product is returned.

- An easy-to-read String output method is also very handy. This should return a String representation of the name and the odds. A form that looks like `1-2 Split (17:1)` works nicely. In Java, this is done as follows.

  ```
  public String toString();
  ```

  In Python, the following declaration is used.

  ```
  def __str__(self):
  ```

  For some tips on how to do this, see Formatting in Java. Python formatting is done more simply, using the `%` operator.

### Formatting in Java

For the very-new-to-Java, there are a variety of ways of implementing `toString`. Those who are more experienced in Java can skip this section.

- `String` concatenation works neatly, but has some caveats. First, it tends to create a lot of intermediate objects. It isn't the best for high-volume, high-performance programs. Second, when assembling numeric results, additional ()'s are required; something that first-time programmers find unexpected.
- `StringBuffer` assembly works a little better. It doesn't create as many intermediate objects as simple `String` concatenation. However, it is a bit more wordy.
- The `java.text.MessageFormat` class is perhaps the nicest way to produce these kinds of formatted strings.

Example of simple String concatenation. In this case, we depend on a certain amount of automatic string conversion. This technique requires that the very first element be a String, and that any arithmetic operations have additional ()'s to permit them to be done first as numeric values before being converted to a string.

**Example 4.2. Java Simple toString Implementation**

```
public String toString() {
    return name + " (" + odds + ":1)"; ❶
```

```
}
```

❶ We assemble a string from the name, some literals, and an implicit conversion of the odds to a string.

Example of StringBuffer construction. In this case, we append a number of strings into the StringBuffer.

**Example 4.3. Java StringBuffer toString Implementation**

```
public String toString() {
    StringBuffer result= new StringBuffer(); ❶
    result.append( name ).append( " (" ).
        append( odds ).append( ":1)" ); ❷
    return result.toString(); ❸
}
```

❶ Create an empty `StringBuffer`.

❷ Append various strings to the `StringBuffer`.

❸ Return a final String from the `StringBuffer`.

Example of using a MessageFormat object. In this case, a simple `String` message template will have the values inserted into it. The `{0}` markers show where values from the array of `Objects` are inserted into the output message. Eventually, the message template can be extracted to a `ResourceBundle`. While not essential for learning OO design, this is a good objective for high-quality software.

**Example 4.4. Java MessageFormat toString Implementation**

```
public String toString() {
    Object[] values= { name, new Integer(odds) }; ❶
    String msgTempl= "{0} ({1}:1)"; ❷
    return MessageFormat.format( msgTempl, values ); ❸
}
```

❶ Create an array of objects that will be converted to Strings and inserted into the message.

❷ Create the template message.

❸ Insert the objects into the template message, returning the new String.

## Deliverables

There are two deliverables for this exercise. Both will have Javadoc comments or Python docstrings.

- The `Outcome` class.
- A class which performs a unit test of the `Outcome` class. The unit test should create a three instances of `Outcome`, two of which have the same name. It should use a number of individual tests to establish

that two `Outcome` with the same name will test true for equality, have the same hash code, and establish that the `winAmount` method works correctly.

# Chapter 5. Bin Class

**Table of Contents**

This chapter will present the design for the `Bin` class. In addition to that, we'll examine the collection classes available in Java and Python. We'll also present present some questions and answers on this particular class and the process of creating a design.

## Overview

The Roulette wheel has 38 bins, identified with a number and a color. Each of these bins defines a number of closely related winning `Outcomes`. At this time, we won't enumerate each of the 38 `Bins` of the wheel and each of the winning `Outcomes` (from two to fourteen in each `Bin`); we'll save that for a later exercise. At this time, we'll define the `Bin` class, and use this class to contain a number of `Outcome` objects.

Two of the `Bins` have relatively few `Outcomes`. Specifically, the 0 `Bin` only contains the basic “0” `Outcome` and the “00-0-1-2-3” `Outcome`. The 00 `Bin`, similarly, only contains the basic “00” `Outcome` and the “00-0-1-2-3” `Outcome`.

The other 36 `Bins` contain the straight bet, split bets, street bet, corner bets, line bets and various outside bets (column, dozen, even or odd, red or black, high or low) that will win if this `Bin` is selected. Each number bin has from 12 to 14 individual winning `Outcomes`.

Some `Outcomes`, like red or black, occur in as many as 18 individual `Bins`. Other `Outcomes`, like the straight bet numbers, each occur in only a single `Bin`. We will have to be sure that our `Outcome` objects are shared appropriately by the `Bins`.

Since a `Bin` is just a collection of individual `Outcome` objects, we have to select a collection class to contain the objects. In Java we have five basic choices, with some variations based on performance needs. In Python, we have two basic choices.

## Java Collections

The Java collections framework offers us five basic choices for defining an object that is a container for other objects.

- **Simple Arrays.** We can always declare a collection of `Outcome` objects as follows: `Outcome[] bin1 = { Outcome("Red",1), Outcome("1",35) };`. This does almost everything that we need it to do. Since our relationship between a `Bin` and the collection of `Outcomes` is relatively fixed, this kind of collection has some appeal.

- **`java.util.Vector`.** With a `Vector`, we have the flexibility of easy addition of an `Outcome` to the collection. We also have the power of an `Iterator` to visit every member of the collection.

  A `Vector` has an implication of non-sequential access to the elements. In our case, we won't be using this; most of our collections will be visited in order, as we determine which individual bets on the table match the `Bin`'s collection of winning `Outcomes`.

- **`java.util.Set`.** A `Set` offers easy addition of elements, an `Iterator` to visit the elements. Additionally, it assures that each element occurs only once. The semantics of a mathematical set are precisely what we want for each `Bin` on a wheel: it is an unordered collection of elements, each element occurs at most one time.

  The `Set` is appealing because the definition precisely matches our need. Additionally, it is possible that a `Set` performs faster than a `Vector` or `List`. The reason it can be faster is that it does not have to keep the elements in a particular order.

- **`java.util.List`.** A `List` offers easy addition of elements, an `Iterator` to visit the elements. Like a `Vector`, a `List` keeps the elements in a particular order.

  A `List` has an implication of strictly sequential access to the elements. In our case, this is generally true. Most of our collections will be built in order and visited in order, as we determine which individual bets on the table match the `Bin`'s collection of winning `Outcomes`. The order, however, isn't significant, so this feature is of relatively little value.

- **`java.util.Map`.** A map is used to associate a key with a value. This key-value pair is called an *entry* in the map. We don't need this feature at all. A map does more than we need for representing the bins on a wheel.

Having looked at the fundamental collection varieties, we will elect to use a `Set`. Our next step is to choose a concrete implementation. There are three alternatives.

- **`java.util.HashSet`.** This uses a *hash code* to manage the elements in the set. The hash code can be computed almost instantly, allowing for rapid insert and retrieval. The hash code is mapped to buckets in an internal table. However, a large amount of storage is wasted by the need for empty buckets in the internal table. This trades off storage for speed.

- **`java.util.LinkedHashSet`.** This adds a doubly-linked list that preserves the insertion order. This is not appropriate for what we are doing, as the insertion order is largely irrelevant.

- **`java.util.TreeSet`.** This uses a *binary red-black tree* algorithm to store the elements of the set. The insertion time depends on the logarithm of the size of the tree, but the storage is minimized. This seems like the ideal candidate for representation of each `Bin`.

### Python Collections

There are three basic Python types that are a containers for other objects.

- **Immutable Sequence or tuple.** A tuple is immutable sequence of objects. This is the kind of collection we need, since the elements of a `Bin` don't change.

- **Mutable Sequence or list.** A list is a sequence of objects that can be changed. While handy for the initial construction of the bin, this isn't really useful because the contents of a bin don't change once they have been enumerated.

- **Mapping or dictionary.** A dictionary associated a key with a value. This key-value pair is called an *item* in the map. We don't need this feature at all. A map does more than we need for representing a `Bin`.

Having looked at the fundamental collection varieties, we will elect to use a `tuple`.

## Questions and Answers

**Q:** Why wasn't `Bin` in the design overview?

**A:** The definition of the Roulette game did mention the 38 bins of the wheel. However, when identifying the nouns, it didn't seem important. Then, as we started designing the `Wheel` class, the description of the wheel as 38 bins came more fully into focus. Rework of the preliminary design is part of detailed design. This is the first of several instances of rework.

**Q:** Why introduce an entire class for the bins of the wheel? Why can't the wheel be an array of 38 individual arrays?

**A:** There are two reasons for introducing `Bin` as a separate class: to improve the fidelity of our object model of the problem, and to reduce the complexity of the `Wheel` class. The definition of the game describes the wheel as having 38 bins, each bin causes a number of individual `Outcomes` to win. Without thinking too deeply, we opted to define the `Bin` class to hold a collection of `Outcomes`. At the present time, we can't foresee a lot of processing that is the responsibility of a `Bin`. But allocating a class permits us some flexibility in assigning responsibilities there in the future.

Additionally, looking forward, it is clear that the `Wheel` class will use a random number generator and will pick a winning `Bin`. In order to keep this crisp definition of responsibilities for the `Wheel` class, it makes sense to delegate all of the remaining details to another class.

**Q:** Isn't an entire class for bins a lot of overhead?

**A:** The short answer is no, class definitions are almost no overhead at all. Class definitions are part of the compiler's world; at run-time they amount to a few simple persistent objects that define the class. It's the class instances that cause run-time overhead.

In a system where were are counting individual instruction executions at the hardware level, this additional class may slow things down somewhat. In most cases, however, the extra few instructions required to delegate a method to an internal object is offset by the benefits gained from additional flexibility.

**Q:** How can you introduce Set, List, Vector when these don't appear in the problem?

**A:** We have to make a distinction between the classes that are uncovered during analysis of the problem in general, and classes are that just part of the implementation of this particular solution. This emphasizes the distinction between *the problem* as described by users and *a solution* as designed by software developers. The collections framework are part of a solution, and hinted at by the definition of the problem. Generally, these solution-oriented classes are part of frameworks or libraries that came with our tools, or that we can license for use in our application. The problem-oriented classes, however, are usually unique to our problem.

## Java Design

`Bin` contains a collection of `Outcomes` which reflect the winning bets that are paid for a particular bin on a Roulette wheel. In Roulette, each spin of the wheel has a number of `Outcomes`. Example: A spin of 1, selects the “1” bin with the following winning `Outcomes`: “1”, “Red”, “Odd”, “Low”, “Column 1”, “Dozen 1-12”, “Split 1-2”, “Split 1-4”, “Street 1-2-3”, “Corner 1-2-4-5”, “Five Bet”, “Line 1-2-3-4-5-6”, “00-0-1-2-3”, “Dozen 1”, “Low” and “Column 1”. These are collected into a single `Bin`.

### Fields

- `Set outcomes ;`

  Holds the connection of individual `Outcomes`.

For a discussion on the type declaration used for `outcome`, see Deferred Binding in Java.

#### Deferred Binding in Java

Python programmers can skip this section. Because Python uses run-time bindings, it doesn't use variable or parameter type declarations. Java, however, seeks to do as much compile-time binding as possible, and requires variable and parameter type declarations.

Some programmers note that our field declarations use interface names, like `Set`, not one of the concrete class implementations of that interface like `HashSet`. We strongly recommend declaring variables to be the highest-level class or interface that has the desired features. This gives the maximum flexibility to change the concrete class as needed.

In this case, we want only a few methods of the `Set` interface. Any of the available concrete implementations of `Set` would work perfectly here. By declaring the `outcomes` field of `Bin` with the interface, we are free to change the concrete class at some later time. Any concrete class that implements the necessary interface can be used.

Why would we change the concrete class? After all, we've analyzed the problem from several points of view and selected `TreeSet`. Typically, selecting a collection class represents a trade-off of memory, speed, or other features. These trade-off priorities are subject to considerable change. We have no reason for any design decision to be “cast in concrete”; and a formal declaration of a particular class is something that firmly fixes a design feature. We find that one consequence of our ignorance of the overall application and the uses to which it will be pu is that our assumptions may prove to be invalid, and we need to be able to make changes without devastating the design of our application.

Rather than make it difficult to switch to another implementation of `Set`, we declare the field with the highest-level interface or superclass. Then we make the concrete class decision in the constructor, deferring the final decision until run-time. A single line of source implements the final choice, simplifying the change process.

The logical extension of this policy is to focus all construction of new objects into builder objects as much as possible. In order to create a flexible application, we can use the **Abstract Factory** design pattern to create all new instances where change if type is expected. In this design pattern, the factory makes the final decision of which class to construct.

## Constructors

In addition to the default constructor that makes an empty `Bin`, Java programmers may find it helpful to create a two additional constructors to initialize the collection from other collections.

- `Bin();`

  Creates an empty `Bin`. `Outcomes` can be added to it later.

- `Bin(Outcome[] outcomes);`

  Creates an empty `Bin` using the `this()` statement to invoke the default constructor. It then loads that collection using elements of the given array.

- `Bin(Collection outcomes);`

Creates an empty Bin using the this() statement to invoke the default constructor. It then loads that collection using an iterator over the given Collection. This relies on the fact that all classes that implement Collection will provide the iterator; the constructor can convert the elements of the input collection to a proper Set.

The array constructor will initialize the outcomes Set from an array of Outcomes. This allows the following kind of constructor call from another class.

**Example 5.1. Java Bin Construction**

```
Outcome five= new Outcome( "00-0-1-2-3", 6 );
Outcome[] ocZero = {
    new Outcome("0", 35 ), five }; ❶
Outcome[] ocZeroZero = {
    new Outcome("00", 35 ), five }; ❷
Bin zero= new Bin( ocZero ); ❸
Bin zerozero= bew Bin( ocZeroZero );
```

❶ This creates ocZero, which is an array of references to two objects: the “0” Outcome and the “00-0-1-2-3” Outcome.

❷ This creates ocZeroZero, which is an array of references to two objects: the “00” Outcome and the “00-0-1-2-3” Outcome.

❸ This creates zero, which is the final Bin, built from ocZero, which has both “0” and “five”.

## Methods

- `void add(Outcome outcome);`

  Adds an Outcome to this Bin. This can be used by a builder to construct all of the bets in this Bin. Since this class is really just a façade over the underlying collection object, this method can simply delegate the real work to the underlying collection.

- `public String toString();`

  An easy-to-read String output method is also very handy. This should return a String representation of the list of Outcomes in this Bin.

  For some tips on how to implement this, see Formatting in Java.

# Python Design

Bin contains a collection of Outcomes which reflect the winning bets that are paid for a particular bin on a Roulette wheel. In Roulette, each spin of the wheel has a number of Outcomes. Example: A spin of 1, selects the “1” bin with the following winning Outcomes: “1”, “Red”, “Odd”, “Low”, “Column 1”, “Dozen 1-12”, “Split 1-2”, “Split 1-4”, “Street 1-2-3”, “Corner 1-2-4-5”, “Five Bet”, “Line 1-2-3-4-5-6”, “00-0-1-2-3”, “Dozen 1”, “Low” and “Column 1”. These are collected into a single Bin.

## Fields

- `outcomes = ()`

  Holds the connection of individual `Outcomes`.

## Constructors

Python programmers should provide an initializer that uses the `*` modifier so that all of the individual arguments appear as a single list within the initializer.

- `def __init__(self, *outcomes):`

This constructor can be used as follows.

**Example 5.2. Python Bin Construction**

```
five= Outcome( "00-0-1-2-3", 6 )
zero= Bin( Outcome("0",35), five ) ❶
zerozero= Bin( Outcome("00",35), five ) ❷
```

❶ This creates `zero` `Bin`, which is based on references to two objects: the “0” `Outcome` and the “00-0-1-2-3” `Outcome`.

❷ This creates `zerozero`, which is based on references to two objects: the “00” `Outcome` and the “00-0-1-2-3” `Outcome`.

## Methods

- `def  add(self, outcome):`

  Adds an `Outcome` to this `Bin`. This can be used by a builder to construct all of the bets in this `Bin`. Since this class is really just a façade over the underlying collection object, this method can simply delegate the real work to the underlying collection. Note that a tuple is immutable; unlike a list it does not have an `append` method. Instead, a tuple is constructed by using the “+” operator which creates a new tuple from two input tuples.

  **Example 5.3. Python Appending Outcomes to A Tuple**

  ```
  self.outcomes = self.outcomes + outcome
  ```

- `def __str__(self):`

  An easy-to-read String output method is also very handy. This should return a String representation of the list of `Outcomes` in this `Bin`. A handy technique for displaying collections is the following. This maps the `str` function to each element of `self.outcomes`, then joins the resulting string with “,” separators.

**Example 5.4. Python String Conversion of a Tuple of Outcomes**

```
def __str__( self ):
    return ', '.join( map(str,self.outcomes) )
```

## Deliverables

There are two deliverables for this exercise. Both will have Javadoc comments or Python docstrings.

- The `Bin` class.
- A class which performs a unit test of the `Bin` class. The unit test should create several instances of `Outcome`, two instances of `Bin` and establish that `Bin`s can be constructed from the `Outcome`s.

  Programmers who are new to OO techniques are sometimes confused when reusing individual `Outcome` instances. This unit test is a good place to examine the ways in which object *references* are shared. A single `Outcome` object can be referenced by several `Bin`s. We will make increasing use of this in later sections.

# Chapter 6. Wheel Class

**Table of Contents**

This chapter builds on the previous two chapters, creating a more complete composite object from the `Outcome` and `Bin` classes we have already defined. We'll introduce some basic subclass constructor techniques, also.

## Overview

The wheel has two responsibilities: it is a container for the `Bin`s and it picks one of the `Bin`s at random. We'll also have to look at how to initialize the various `Bin`s.

**Container Implementation.** Since the `Wheel` is 38 `Bin`s, it is a collection. We can review our survey of the Java collections in Java Collections and the Python collections in Python Collections for some guidance here. In this case, the choice of `Bin` will be selected by a random numeric index. For Java programmers, this makes the `java.util.Vector` very appealing. Python programmers will find that a `List` will do very nicely.

One consequence of using a `Vector` is that we have to choose an index for the various `Bins`. While each `Bin` contains a variety of individual `Outcomes`, the single number `Outcome` is unique to each `Bin`. The numbers 1 to 36 become the index to their respective `Bins`. We have a small problem, however, with 0 and 00: we need two separate indexes. While 0 is a valid index into a `Vector`, what do we do with 00?

Since the index of the `Bin` doesn't have any significance at all, we can assign the `Bin` that has the 00 `Outcome` to position 37 in the `Vector`. This gives us a unique place for all 38 `Bins`.

**Random Selection.** In order for the `Wheel` to select a `Bin` at random, we'll need a random number from 0 to 37 that we can use an an index. The random number generator in `java.util.Random` does everything we need. We can use the generator's `public int nextInt(int n);` method to return integers.

Python programmers can use the `random` module. This module offers a `choice` function which picks a random value from a sequence. This is ideal for returning a randomly selected `Bin` from our list of `Bins`. For some cautions on casual use of modules in Python, see Using Python Modules.

**Initialization.** Each instance of `Bin` has a list of `Outcomes`. The 0 and 00 `Bins` only have two `Outcomes`. The other numbers have anywhere from twelve to fourteen `Outcomes`. Constructing the entire collection of `Bins` would be a tedious undertaking. We'll apply a common OO design technique of *deferred binding* and work on that algorithm later, after we have the basic design for the `Wheel` finished.

### Using Python Modules

Java programmers can skip this warning. Java wraps all functions and variables in class declarations, but Python provides an additional kind of packaging, called a *module*.

In addition to class definitions, Python modules typically offer *convenience functions*. These are functions that are bound to the module itself instead of any particular class within the module. Since these functions are not part of a specific class, it can be confusing when attempting to create subclasses.

Looking forward toward the section on testing, we'll want to introduce a non-random number generator. This can be difficult if we are not careful of how we use the `random` module. We are warned in the Python documentation that the convenience functions in the `random` module are actually bound methods of a *hidden instance* of the `random.Random` class.

As a general principle, module-level convenience functions should be used with caution. They can simplify developing an application, but their hidden features can make it difficult to extend or modify an application. For our purposes, we won't use the convenience functions; instead, we'll create an instance of `random.Random`.

## Design

`Wheel` contains the 38 individual bins on a Roulette wheel, plus a random number generator. It can select a `Bin` at random, simulating a spin of the Roulette wheel.

For those new to Java, see Java Subclass Constructors.

### Java Subclass Constructors

When a subclass depends on a superclass constructor, the following syntax is used.

**Example 6.1. Java Subclass Declaration**

```
class PlayerRandom extends Player {
    public PlayerRandom( Table aTable ) {
        super( aTable );
    }
}
```

For those new to Python, see Python Subclass Constructors.

### Python Subclass Constructors

When a subclass depends on a superclass constructor, the following syntax is used.

**Example 6.2. Python Subclass Declaration**

```
class PlayerRandom( Player ):
    def __init__( self, aTable ):
        Player.__init__( self, aTable )
```

## Fields

- Java: `java.util.Vector bins = new Vector( 38 );`

  Python: `bins = 38*[None]`

  Contains the individual `Bin` instances.

- Java: `java.util.Random rng = new java.util.Random();`

  Python: `rng = random.Random()`

  Generates the next random number, used to select a `Bin` from the `bins` collection.

## Constructors

- `Wheel();`

  Creates a new wheel with 38 empty `Bins`. It will also create a new random number generator instance.

  At the present time, this does not do the full initialization of the `Bins`. We'll rework this in a future exercise.

## Methods

-
  ```
  addOutcome(int number,
             Outcome outcome);
  ```

  Adds the given `Outcome` to the `Bin` with the given number.

- `next();`

  Generates a random number between 0 and 37, and returns the randomly selected `Bin`.

  Java: Be sure to note that the `java.util.Random` `nextInt` method uses the size of the `bins` collection to return values from 0 to the size of the collection. Typically there are 38 values, numbered from 0 to 37.

  Python: the `choice` function of the `random` module will select one of the available `Bins` from the `bins` list.

  In later chapters, we'll revisit ways to test this method. For now, it returns a random result that's difficult to unit test.

- `Bin getBin(int aBin);`

  Returns the given `Bin` from the internal collection.

## Deliverables

There are three deliverables for this exercise. The new class and the unit test will have Javadoc comments or Python docstrings.

- The `Wheel` class.
- A class which performs a unit test of building the `Wheel` class. The unit test should create several instances of `Outcome`, two instances of `Bin`, and an instance of `Wheel`. The unit test should establish that `Bins` can be added to the `Wheel`.
- A class which performs a demonstration of selecting random values from the `Wheel` class. Since the `Bins` will be returned in a random order, this is difficult to call a formal test. The demonstration should include the following.

  1. Create several instances of `Outcome`.
  2. Create two instances of `Bin` that use the available `Outcomes`.
  3. Create one instance of `Wheel` that uses the two `Bins`.
  4. A number of calls to the `next` method should return randomly selected `Bins`.

Note that the sequence of random numbers is fixed by the seed value. The default constructor for a random number generator creates a seed based on the system clock. Your unit test can set a particular seed value for the random number generator within the instance of `Wheel`; this will deliver a fixed sequence of numbers that can be used to get a consistent result.

# Chapter 7. Bin Builder Class

**Table of Contents**

This is a rather long chapter, which describes a number of design considerations surrounding `Outcome`, `Bin` and `Wheel`. The second section presents a number of algorithms to group `Outcomes` based on the geometry of the table. These algorithms are presented at a high level, leaving much of the detailed design to the student.

## Overview

It is clear that enumerating each `Outcome` in the 38 `Bins` is a tedious undertaking. Most `Bins` contain about fourteen individual `Outcomes`. It is often helpful to create a class that is used to build an instance of another class. This is a design pattern sometimes called a **Builder**. We'll design an object that builds the various `Bins` and assigns them to the `Wheel`. This will fill the need left open in the design of the `Wheel` class.

Additionally, we note that the complex algorithms to construct the `Bins` are only tangential to the operation of the `Wheel` object. While not essential to the design of the `Wheel` class, we find it is often helpful to segregate these rather complex builder methods into a separate class.

The `BinBuilder` class will have a method that enumerates the contents of each of the 36 number `Bins`, building the individual `Outcome` instances. We can then assign these `Outcome` objects to the `Bins` of a `Wheel` instance. We will use a number of steps to create the various types of `Outcomes`, and depend on the `Wheel` to assign each `Outcome` object to the correct `Bin`.

Looking at the layout of a Roulette table gives us a number of geometric rules for determining the various `Outcomes` that are combinations of individual numbers. These rules apply to the numbers from one to thirty-six. A different -- and much simpler -- set of rules applies to 0 and 00. First, we'll survey the table geometry, then we'll develop specific algorithms for each kind of bet.

- **Split Bets.** Each number is adjacent to two, three or four other numbers. The four corners (1, 3, 34, and 36) only participate in two split bets. The center column of numbers (5, 8, 11, ..., 32) each participate in four split bets. The remaining “edge” numbers participate in three split bets. While this is moderately complex, the bulk of the layout (from 4 to 32) can be handled with a simple rule to distinguish the center column from the edge columns. The ends (1, 2, 3, 34, 35 and 36) are a little more complex.

- **Street Bets.** Each number is a member of one of the twelve street bets.
- **Corner Bets.** Each number is a member of one, two or four corner bets. As with split bets, the bulk of the layout can be handled with a simple rule to distinguish the column, and hence the “corners”. A number in the center column (5, 8, 11, ..., 32) is a member of four corners. At the ends, 1, 3, 34, and 36, are members of just one corner. All of the remaining numbers are along an edge and are members of two corners.
- **Line Bets.** Six numbers comprise a line; each number is a member of one or two lines. The ends (1, 2, 3 and 34, 35, 36) are each part of a single line. The remaining 10 rows are each part of two lines.
- **Dozen Bets.** Each number is a member of one of the three dozens. The three ranges are from 1 to 12, 13 to 24 and 25 to 36, making it very easy to associate numbers and ranges.
- **Column Bets.** Each number is a member of one of the three columns. Each of the columns has a number numeric relationship. The values are 3*c*+1, 3*c*+2, and 3*c*+3, where *c* varies from 0 to 11.
- **The Even-Money Bets.** These include Red, Black, Even, Odd, High, Low. Each number has three of the six possible even money `Outcomes`. An easy way to handle these is to create the 6 individual `Outcome` instances. For each number, *n*, individual if-statements can be used to determine which of the `Outcome` objects are associated with the given `Bin`.

The `Bins` for zero and double zero can easily be enumerated. Each bin has a straight number bet `Outcome`, plus the Five Bet `Outcome` (00-0-1-2-3, which pays 6:1).

One other thing we'll probably want are handy names for the various kinds of odds. While can define an `Outcome` as `Outcome( "Number 1", 35 )`, this is a little opaque. A slightly nicer form is `Outcome( "Number 1", RouletteGame.StraightBet )`. These are specific to a game, not general features of all `Outcomes`. We haven't designed the game yet, but we can provide a stub class with these these outcome odds definitions.

## Internationalization and Localization

An an advanced topic, we need to avoid *hard coding* the names of the bets. Both Java and Python provide extensive tools for localization (l10n) of programs. Since both applications already use Unicode strings, they support non-Latin characters, handling much of the internationalization (i18n) part of the process.

**Java Localization.** This application's bet names should be fetched from resource bundles so that we can change the bet names without making changes to `BinBuilder` and all of the various subclasses of `Player` that use various kinds of bets.

There are number of localization features in Java. We can specify a `Locale` object, which provides a number of defaults for the formatters in the `java.text` package and resource bundles with Strings that will be displayed to people.

We won't dwell on the l10n issue. However, the right preparation for l10n is to isolate all Strings used for messages, and format all dates and numbers with formatters found in the `java.text` package. In this case, our `Outcome` names may be displayed, and should be isolated into a separate object. Even something as simple as `blackBetName = "Black";` will set the stage for fetching strings from resource bundles.

**Python Localization.** Python localization depends on the `locale` and `gettext` modules. The `locale` module provides a number of functions and constants to help format dates and times for the user's selected locale. The `gettext` module provides a mechanism for getting translated text from a message catalog with messages in a variety of languages.

We won't dwell on the l10n issue. However, the right preparation for l10n is to isolate all Strings used for messages, and format all dates and numbers with formatters found in the `locale` module. In this case, our `Outcome` names may be displayed, and should be isolated into a separate object. Even something as simple as `blackBetName = _("Black")` will set the stage for fetching strings from a `gettext` message catalog.

In order to define the `_(string)` function, the following fragment should be used. While not ubiquitous in Python programs, doing this now establishes a standard practice that will permit easy localization of an application program.

**Example 7.1. Python Localization**

```
import gettext
gettext.NullTranslations().install() ❶
print _("String To Be Translated") ❷
```

❶ This constructs an instance of `NullTranslations`. This is then installed as a function named _, which finds a translation for the default C-locale string. This class does nothing; but it can be replaced with the `GNUTranslations` class, which uses a message catalog to replace the default strings with localized strings.

❷ This shows how to use the _ function to translate a default C-locale string to a localized string.

## Algorithms

Straight bet `Outcomes` are the easiest to generate.

**Procedure 7.1. Generating Straight Bets**

- **For All Numbers.** For each number, *n*, from 1 to 36:

  a. **Create Outcome.** Create an `Outcome` from the number, *n*, with odds of 35:1.

  b. **Assign to Bin.** Assign this new `Outcome` to `Bin` *n*.

Split bet `Outcomes` are more complex because of the various cases: corners, edges and down-the-middle.

We note that there are two kinds of split bets: left-right pairs and up-down pairs. The left-right pairs all have the form (*n*, *n*+1). The up-down paris have the form (*n*, *n*+3). We can look at the number 5 as being part of 4 different pairs: (4,4+1), (5,5+1), (2,2+3), (5,5+3). The corner number 1 is part of 2 split bets: (1,1+1), (1,1+3).

We can generate the "left-right" split bets by iterating through the left two columns; the numbers 1, 4, 7, ..., 34 and 2, 5, 8, ..., 35.

**Procedure 7.2. Generating Split Bets**

- **For All Rows.** For each row, *r*, from 0 to 11:

  a. **First Column Number.** Compute number, *n* as 3*r*+1. This will create values 1, 4, 7, ..., 34.

  b. **Column 1-2 Split.** Create a "*n*, *n*+1" split `Outcome` with odds of 17:1.

  c. **Assign to Bins.** Associate this object with two `Bins`: *n* and *n*+1.

  d. **Second Column Number.** Compute number, *n* as 3*r*+2. This will create values 2, 5, 8, ..., 35.

  e. **Column 2-3 Split.** Create a "*n*, *n*+1" split `Outcome`.

  f. **Assign to Bins.** Associate this object to two `Bins`: *n* and *n*+1.

Similarly, for the numbers 1 through 33, we can generate the "up-down" split bets. For each number, *n*, we generate a "*n*, *n*+3" split bet. This `Outcome` belongs to two `Bins`: *n* and *n*+3.

Street bet `Outcomes` are very simple.

We can generate the street bets by iterating through the twelve rows of the layout.

**Procedure 7.3. Generating Street Bets**

- **For All Rows.** For each row, *r*, from 0 to 11:

  a. **First Column Number.** Compute number, *n* as 3*r*+1. This will create values 1, 4, 7, ..., 34.

  b. **Street.** Create a "*n*, *n*+1, *n*+2" street `Outcome` with odds of 11:1.

  c. **Assign to Bins.** Associate this object to three `Bins`: *n*, *n*+1, *n*+2.

Corner bet `Outcomes` are as complex as split bets because of the various cases: corners, edges and down-the-middle.

Eacb corner has four numbers, *n*, *n*+1, *n*+3, *n*+4. We can generate the corner bets by iterating through the numbers 1, 4, 7, ..., 31 and 2, 5, 8, ..., 32. For each number, *n*, we generate four corner bets: "*n*, *n*+1, *n+3*, *n*+4" corner bet. This `Outcome` object belongs to four `Bins`.

We generate corner bets by iterating through the lines between rows and columns. There are two lines between the three columns, and 11 lines between the 12 rows. The column lines are to the right of the first two columns. Similarly the row lines are below the first 11 rows.

**Procedure 7.4. Generating Corner Bets**

- **For All Lines Between Rows.** For each line below a row, *r*, from 0 to 10:

  a. **First Column Number.** Compute number, *n* as 3*r*+1. This will create values 1, 4, 7, ..., 31.

  b. **Column 1-2 Corner.** Create a "*n*, *n*+1, *n*+3, *n*+4" corner `Outcome` withs odds of 8:1.

  c. **Assign to Bins.** Associate this object to four `Bins`: *n*, *n*+1, *n*+3, *n*+4.

  d. **Second Column Number.** Compute number, *n* as 3*r*+2. This will create values 2, 5, 8, ..., 32.

  e. **Column 2-3 Corner.** Create a "*n*, *n*+1, *n*+3, *n*+4" corner `Outcome` withs odds of 8:1.

  f. **Assign to Bins.** Associate this object to four `Bins`: *n*, *n*+1, *n*+3, *n*+4.

Line bet `Outcomes` are similar to street bets. However, these are based around the 11 lines between the 12 rows.

For lines *s* numbered 0 to 10, the numbers on the line bet can be computed as follows: 3*s*+1, 3*s*+2, 3*s*+3, 3*s*+4, 3*s*+5, 3*s*+6. This `Outcome` object belongs to six individual `Bins`.

**Procedure 7.5. Generating Line Bets**

- **For All Lines Between Rows.** For each row, *r*, from 0 to 10:

  a. **First Column Number.** Compute number, *n* as 3*r*+1. This will create values 1, 4, 7, ..., 31.

  b. **Line.** Create a "*n*, *n*+1, *n*+2, *n*+3, *n*+4, *n*+5" line `Outcome` withs odds of 5:1.

  c. **Assign to Bins.** Associate this object to six `Bins`: *n*, *n*+1, *n*+2, *n*+3, *n*+4, *n*+5.

Dozen bet `Outcomes` require enumerating all twelve numbers in each of three groups.

**Procedure 7.6. Generating Dozen Bets**

- **For All Dozens.** For each dozen, *d*, from 0 to 2:

  a. **Create Dozen.** Create an `Outcome` for dozen *d*+1 with odds of 2:1.

  b. **For All Numbers.** For each number, *m*, from 0 to 11:

     i. **Assign to Bin.** Associate this object to `Bin` 12*d*+*m*+1.

Column bet `Outcomes` require enumerating all twelve numbers in each of three groups. While the outline of the algorithm is the same as the dozen bets, the enumeration of the individual numbers in the inner loop is slightly different.

**Procedure 7.7. Generating Column Bets**

- **For All Columns.** For each column, *c*, from 0 to 2:
    a. **Create Column.** Create an `Outcome` for column *c*+1 with odds of 2:1.
    b. **For All Rows.** For each row, *r*, from 0 to 11:
        i. **Assign to Bin.** Associate this object to `Bin` 3*r*+*c*+1.

The even money bet `Outcomes` are relatively easy to generate.

**Procedure 7.8. Generating Even-Money Bets**

1. Create the Red outcome, with odds of 1:1.
2. Create the Black outcome, with odds of 1:1.
3. Create the Even outcome, with odds of 1:1.
4. Create the Odd outcome, with odds of 1:1.
5. Create the High outcome, with odds of 1:1.
6. Create the Low outcome, with odds of 1:1.
7. **For All Numbers.** For each number, *n*, from 1 to 36:
    a. **Low?** If *n* is between 1 and 18, associate the low `Outcome` with `Bin` *n*.

       **High?** Otherwise, *n* is between 19 and 36, associate the high `Outcome` with `Bin` *n*.
    b. **Even?** If *n* % 2 is zero, associate the even `Outcome` with `Bin` *n*.

       **Odd?** Otherwise, *n* % 2 is 1, associate the odd `Outcome` with `Bin` *n*.
    c. **Red?** If *n* is one of 1, 3, 5, 7, 9, 12, 14, 16, 18, 19, 21, 23, 25, 27, 30, 32, 34, or 36, associate the red `Outcome` with `Bin` *n*.

       **Black?** Otherwise, associate the black `Outcome` with `Bin` *n*.

## Design

`BinBuilder` creates the `Outcomes` for all of the 38 individual `Bin` on a Roulette wheel.

### Constructors

- `BinBuilder();`

  Initializes the `BinBuilder`.

### Methods

- `void buildBins(Wheel aWheel);`

  Creates the `Outcome` instances and uses the `addOutcome` method to place each `Outcome` in the appropriate `Bin` of *`aWheel`*.

  There should be nine separate methods to generate the straight bets, split bets, street bets, corner bets, line bets, dozen bets and column bets, even money bets and the special case of zero and double zero. Each of the methods will be relatively simple and easy to unit test. Details are provided in Algorithms.

## Deliverables

There are three deliverables for this exercise. The new classes will have Javadoc comments or Python docstrings.

- The `BinBuilder` class.
- A class which performs a unit test of the `BinBuilder` class. The unit test invoke each of the various methods that create `Outcome` instances.
- Rework the unit test of the `Wheel` class. The unit test should create and initialize a `Wheel`. It can use the `getBin` method to check selected `Bins` for the correct `Outcomes`.

# Chapter 8. Bet Class

### Table of Contents

In addition to the design of the `Bet` class, this chapter also presents some additional questions and answers on the nature of an object, identity and state change. This continues some of the ideas from On Object Identity

## Overview

A `Bet` is an amount that the player has wagered on a specific `Outcome`. This class has the responsibilty for maintaining the association between an amount, an `Outcome`, and a specific `Player`.

This is the classic *record declaration*: a passive association among data elements. The only methods we can see are three pairs of *getters and setters* to get and set each of the three attributes.

The general scenario is to have a `Player` construct a number of `Bet` instances. The wheel is spun to select a winning `Bin`. Then each of the `Bet` objects will be checked to see if they are winners or losers. A winning `Bet` has an `Outcome` that matches one in the winning `Bin`; winners will return money to the `Player`. All other bets are losers, which remove the money from the `Player`.

**Building Bets.** In the long run, we'll need to build a variety of bets. Building a `Bet` involves two parts: an `Outcome` and an amount. There are several places to get Outcomes. First, we can create an Outcome object as part of constructing a Bet. Here's what it might look like in Java.

```
Bet myBet= new Bet( new Outcome("red",2), 25 )
```

A better choice is to get `Outcome` obects from the `Wheel`. To do this, we'd have to make sure that we saved `Outcomes` from the `BinBuilder`. We'd also have add specific `Outcome` getters to the `Wheel`. We could, for example, include a `getBlack` method that returns an instance of the black `Outcome`. In Python, for example, we might have a method function like the following.

```
class Wheel( object ):
...
    def getBlack( self ):
        return self.black
```

A third approach is to keep a Map (in Python, a dictionary) that maps an `Outcome`'s string name to the relevant `Outcome` object. Our `BinBuilder` can accumulate this `Map`, and we can get `Outcomes` out of the Map with a getter method like the following.

```
Outcome getOutcome( String name ) {
    return outcomeMap.get(name);
}
```

For now, we'll build `Outcomes` manually in order to produce a good test of the `Bet` class.

## Questions and Answers

Q: Why not update each Outcome with the amount of the bet?
Q: Does an individual bet really have unique identity? Isn't it just anonymous money?

**Q:** Why not update each `Outcome` with the amount of the bet?

**A:** We are isolating the static definition of the `Outcome` from the presence or absence of an amount wagered. Note that the `Outcome` is shared by the wheel's `Bins`, and the available betting spaces on the `Table`, possibly even the `Player` class. Also, if we have multiple `Player`, then we need to distinguish bets placed by the individual players.

Changing a field's value has an implication that the thing has changed state. In Roulette, there isn't any state change in the definition of an `Outcome`. However, when we look at Craps, we will see that changes in the game's state will enable and disable whole sets of `Outcomes`.

**Q:** Does an individual bet really have unique identity? Isn't it just anonymous money?

**A:** Yes, the money is anonymous. In a casino, the chips all look alike. However, the placement of the bet, really does have unique identity. A `Bet` is owned by a particular player, it lasts for a specific duration, it has a final outcome of won or lost. When we want to create summary statistics, we could do this by saving the individual `Bet` objects. We could update each `Bet` with a won or lost indicator, then we can total the wins and losses.

This points up another reason why we know a `Bet` is an object in its own right: it changes state. A bet that has been placed can change to a bet that was won or a bet that was lost.

## Design

`Bet` associates an amount and an `Outcome`. In a future round of design, we can also associate a it with a `Player`.

### Fields

- `int amountBet ;`

  The amount of the bet.

- `Outcome outcome ;`

  The outcome on which the bet is placed.

### Constructors

-
  ```
  Bet(int amount,
      Outcome outcome);
  ```

  Initialize the instance variables of this bet.

  For these first exercises, we'll omit the player. We'll come back to this class when necessary, and add that capability back in to this class.

### Methods

- `int winAmount();`

  Uses the `Outcome`'s `winAmount` to compute the amount won, given the amount of this bet. Note that the amount bet must also be added in. A 1:1 outcome (e.g. a bet on Red) pays the amount bet plus the amount won.

- `int loseAmount();`

  Returns the amount bet as the amount lost. This is the cost of placing the bet.

- Java: `public String toString();`

  Python: `def __str__(self):`

  Returns a string representation of this bet. Note that this method will delegate the real work to the `toString` (or `__str__`) method of the `Outcome` (and the `Player`, when that is added).

## Deliverables

There are two deliverables for this exercise. The new classes will have Javadoc comments or Python docstrings.

- The `Bet` class.
- A class which performs a unit test of the `Bet` class. The unit test should create a couple instances of `Outcome`, and establish that the `winAmount` and `loseAmount` methods work correctly.

# Chapter 9. Roulette Table Class

**Table of Contents**

This section provides the design for the `Table` to hold the bets. It also introduces the concepts behind exception handling, and the proper role of exceptions.

## Overview

The `Table` has the responsibility to keep the `Bets` created by the `Player`. Additionally, the house imposes *table limits* on the minimum amount that must be bet and the maximum that can be bet. Clearly, the `Table` has all the information required to evaluation these conditions.

### Note

> Casinos prevent the *Martingale* betting system from working by imposing a table limit on each game. To cover the cost of operating the table game, the casino also imposes a minimum bet. Typically, the maximum is a multiplier of the minimum bet, often in the range of 10 to 50; a table with a $5 minimum might have a $200 limit, a $10 minimum may have only a $300 limit.

It isn't clear where the responsibility lies for determining winning and losing bets. The money placed on `Bets` on the `Table` is “at risk” of being lost. If the bet is a winner, the house pays the `Player` an amount based on the `Outcome`'s odds and the `Bet`'s amount. If the bet is a loser, the amount of the `Bet` is forfeit by the `Player`. Looking forward to stateful games like Craps, we'll place the responsibility for determining winners and losers with the game, and not with the `Table` object.

Our second open question is the timing of the payment for the bet from the player's stake. In a casino, the payment happens when the bet is placed on the table. In our Roulette simulation, this is a subtlety that doesn't have any practical consequences. We could deduct the money as part of bet creation, or we could deduct the money as part of resolving the spin of the wheel. In other games, however, there may several events and several opportunities for additional bets. For example, splitting a hand in blackjack, or placing additional odds bets in Craps. Because we can't allow a player to bet more than their stake, we should deduct the payment as the bet is created.

A consequence of this is a change to our definition of the `Bet` class. We don't need to compute the amount that is lost. Rather than deduct the money when the bet resolved, we've decided that the money is deducted from the `Player`'s stake as part of creating the `Bet`. This will become part of the design of `Player` and `Bet`.

Looking forward a little, a stateful game like Craps will introduce a subtle distinction that may be appropriate for a future subclass of `Table`. When the game is in the point off state, some of the bets on the table are not allowed, and others become inactive. When the game is in the point on state, all bets are allowed and active. In Craps parlance, some bets are “not working” or “working” depending on the game state. This does not apply to the version of `Table` that will support Roulette.

**Container Implementation.** A `Table` is a collection of `Bets`. We need to choose a concrete class for the collection of the bets. We can review our survey of the Java collections in Java Collections and the Python collections in Python Collections for some guidance here. In this case, the bets are placed in no particular order, and are simply visited in an arbitrary order for resolution. We can use a Java `LinkedList` for this. Since the number of bets varies, we can't use a Python `tuple`; a `list` will do.

**Table Limits.** Table limits can be checked by providing a public method `isValid` that compares the total of a new prospective amount plus all existing `Bets` to the table limit. This can be used by the `Player` to evaluate each potential bet prior to creating it.

In the unlikely event of the `Player` object creating an illegal `Bet`, we can also throw (or raise) an exception to indicate that we have a design error that was not detected via unit testing. This should be a subclass of `Exception` that has enough information to debug the problem with the `Player` that attempted to place the illegal bet.

Additionally, the game can check the overall state of a `Player`'s `Bets` to be sure that the table minimum is met. We'll need to provide a public method `isValid` that is used by the game. In the event of the minimum not being met, there are serious design issues, and an exception should be thrown. Generally, this situation arises because of a bug where the `Player` should have declined to bet rather than placing incorrect bets that don't meet the table minimum.

**Bet Resolution.** An important consideration is the collaboration between `Table` and some potential game class for resolving bets. The `Table` has the collection of `Bets`, each of which has a specific `Outcome`. The `Wheel` selects a `Bin`, which has a collection of `Outcomes`. All bets with a winning outcome will be resolved as a winner.

Because some games are stateful, and the winning and losing bets depend on game state, we will defer the details of the collaboration design until we get to the Game class. For now, we'll simply collect the Bets.

**Adding and Removing Bets.** A `Table` contains `Bets`. Instances of `Bet` are added by a `Player`. Later, `Bets` will be removed from the `Table` by the `Game`. When a bet is resolved, it must be deleted. Some games, like Roulette resolve all bets with each spin. Other games, like Craps, involve multiple rounds of placing and resolving some bets, and leaving other bets in play.

For Bet deletion to work, we have to provide a method to remove a bet. When we look at Game and bet resolution we'll return to bet deletion. It's import not to over-design this class at this time; we will often add features as we develop designs for additional use cases.

## Design

There are two classes to design: the `InvalidBet` exception and the `Table` class.

### InvalidBet Exception

`InvalidBet` is thrown when the `Player` attempts to place a bet which exceeds the table's limit.

```
 InvalidBet extends Exception {
}
```

This class simply inherits all features of the superclass.

In Python, the declaration must have a body, and the `pass` statement is used for this purpose.

```
class  InvalidBet ( Exception ):
    pass
```

### Table Class

`Table` contains all the `Bets` created by the `Player`. A table also has a betting limit, and the sum of all of a player's bets must be less than or equal to this limit. We assume a single `Player` in the simulation.

#### Fields

- `int limit ;`

This is the table limit. The sum of a `Player`'s bets must be less than or equal to this limit.

- `List bets ;`

  This is a `LinkedList` of the `Bets` currently active. These will result in either wins or losses to the `Player`.

### Constructors

- `Table();`

  Creates an empty `LinkedList` of bets.

### Methods

- `boolean isValid(Bet bet);`

  Validates this bet. If the sum of all bets is less than or equal to the table limit, then the bet is valid, return `true`. Otherwise, return `false`.

-
  ```
  void placeBet(Bet bet)
      throws InvalidBet;
  ```

  Adds this bet to the list of working bets. If the sum of all bets is greater than the table limit, then an exception should be thrown (Java) or raised (Python). This is a rare circumstance, and indicates a bug in the `Player` more than anything else.

- `ListIterator iterator();`

  Returns a `ListIterator` over the list of bets. This gives us the freedom to change the representation from `LinkedList` to any other `Collection` with no impact to other parts of the application.

  In Python, we can return an iterator over the available list of `Bet` instances. The traditional Python approach is to return the list object itself, rather than an iterator over the list. With the introduction of the *generators* in Python 2.3, however, it can be slightly more flexible to return an iterator rather than the list object.

  Note that we need to be able remove Bets from the table. Consequently, we have to update the list, which requires that we use a `ListIterator`, not an `Iterator`.

- Java: `public String toString();`

  Python: `def __str__(self):`

  reports on all of the currently placed bets.

## Deliverables

There are three deliverables for this exercise. Each of these will have complete Javadoc comments or Python docstring comments.

- An `InvalidBet` exception class. This is a simple subclass of `Exception`.
- The `Table` class.
- A class which performs a unit test of the `Table` class. The unit test should create at least two instances of `Bet`, and establish that these `Bets` are managed by the table correctly.

# Chapter 10. Roulette Game Class

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Between `Player` and `Game`, we have a *chicken-and-egg design problem*. In this chapter, we'll describe the design for `Game` in detail. However, in order to create the deliverables, we have to create a version of `Player` that we can use just to get started. In the long run, we'll need to create a sophisticated hierarchy of players. Rather than digress too far, we'll create a simple player, `Pssenger57` (they always bet on black), which will be the basis for further design in later chapters.

## Overview

The `RouletteGame`'s responsibility is to cycle through the various steps of the game procedure, getting bets from the player, spinning the wheel and resolving the bets. This is an *active* class that makes use of the classes we have built so far. The hallmark of an active class is longer or more complex methods. This is distinct from most of the classes we have considered so far, which have relatively trivial methods that are little more than getters and setters of instance variables.

The sequence of operations in one round of the game is the following.

**Procedure 10.1. A Single Round of Roulette**

1. **Place Bets**

   Notify the `Player` to create `Bets`. The real work of placing bets is delegated to the `Player` class. Note that the money is committed at this point; they player's stake should be reduced as part of creating a `Bet`.

2. **Spin Wheel**

   Get the next spin of the `Wheel`, giving the winning `Bin`, *w*.

3. **Resolve All Bets**

   For each `Bet`, *b* placed by the `Player`:

   a. **Winner?**

      If `Bet` *b*'s `Outcome` is in the winning `Bin`, *w*, then notify the `Player` that `Bet` *b* was a winner and update the `Player`'s stake.

   b. **Loser?**

      If `Bet` *b*'s `Outcome` is not in the winning `Bin`, *w*, then notify the `Player` that `Bet` *b* was a loser. This allows the `Player` to update the betting amount for the next round.

**Matching Algorithm.** This class has the responsibility for matching the collection of `Outcomes` in the `Bin` of the `Wheel` with the collection of `Outcomes` of the `Bets` on the `Table`. We have two collections that must be matched: `Bin` and `Table`. We'll need to structure a loop or nested loops to compare individual elements from these two collections.

We could use a loop to visit each `Outcome` in the winning `Bin`. For each `Outcome`, we would then visit each of the `Bets` contained by the `Table`. A `Bet`'s `Outcome` that matches the `Bin`'s `Outcome` is a winner and is paid off. The other bets are losers. This involves two nested loops: one to visit the winning `Outcomes` of a `Bin` and one to visit the `Bets` of a `Table`.

The alternative is to visit each `Bet` contained by the `Table`. Since the winning `Bin` is defined by a `Set`, we can exploit set membership methods to test for presence or absence of an `Bet`'s `Outcome` in that `Bin`'s `Set`. If the `Bin` contains the `Outcome`, the `Bet` is a winner; otherwise the `Bet` is a loser. This only requires a single loop to visit the `Bets` of a `Table`.

**Player Interface.** The `Game` collaborates with `Player`. We have a "chicken and egg" problem in decomposing the relationship between these classes. We note that the `Player` is really a complete hierarchy of subclasses, each of which provides a different betting strategy. For the purposes of making the `Game` work, we can develop our unit tests with a stub for `Player` that simply places a single kind of `Bet`. We'll call this player "Passenger57" because it always bets on Black. In several future exercises, we'll revisit this design to make more sophisticated players.

For some additional design considerations, see the sidebar Additional Design Considerations. This provides some more advanced game options that our current design can be made to support. We'll leave this as an exercise for the more advanced student.

## Additional Design Considerations

In European casinos, the wheel has a single zero. In some casinos, the zero outcome has a special *en prison* rule: all losing bets are split and only half the money is lost, the other half is a push and is returned to the player. The following design notes discuss the implementation of this additional rule.

This is a payout variation that depends on a single `Outcome`. We will need an additional subclass of `Outcome` that has a more sophisticated losing amount method: it would push half of the amount back to the `Player`'s stake. We'll call this subclass the the `PrisonOutcome` class.

In this case, we have a kind of hybrid resolution: it is a partial loss of the bet. In order to handle this, we'll need to have a `loss` method in `Bet` as well as a `win` method. Generally, the `loss` method does nothing (since the money was removed from the `Player`'s stake when the bet was created.) However, for the `PrisonOutcome` class, the `loss` method returns half the money to the `Player`'.

We can also introduce a subclass of `BinBuilder` that creates only the single zero, and uses this new `PrisonOutcome` subclass of `Outcome` for that single zero. We can call this the `EuroBinBuilder`. The `EuroBinBuilder` does not create the five-way `Outcome` of 00-0-1-2-3, either; it creates a four-way for 0-1-2-3.

After introducing these two subclasses, we would then adjust `Game` to invoke the `loss` method of each losing `Bet`, in case it resulted in a push. For an American-style casino, the `loss` method does nothing. For a European-style casino, the `los` method for an ordinary `Outcome` also does nothing, but the `los` for a `PrisonOutcome` would implement the additional rule pushing half the bet back to the `Player`. The special behavior for zero then emerges from the collaboration between the various classes.

We haven't designed the `Player` yet, but we would have to bear this push rule in mind when designing the player.

The uniform interface between `Outcome` and `PrisonOutcome` is a design pattern called *polymorphism*. We will return to this principle many times.

## Design

There are two classes to design: a stub `Player` that we can use for testing, and the actual `Game`.

### Passenger57 Class

`PlayerStub` constructs a `Bet` based on the `Outcome` named `"Black"`. This is a very persistent player.

We'll need a source for the Black outcome. We have several choices; we looked at these in Building Bets. First, we can build the Black outcome from scratch as a distinct object. This works well for a stub that will only participate in a unit test. However, it's annoying to have to specify the odds each time. Second, we can interrogate the `Wheel` or `BinBuilder` for a specific `Outcome` object. Third, we can generalize this approach by adding a Map to the `Wheel`, and getting `Outcome` objects from the Map.

For now, we can create the black `Outcome` manually.

In the long run, we'll have to define a `Player` superclass, and make this class a proper subclass of `Player`. However, our focus now is on getting the `Game` designed and built.

### Fields

- `Outcome black = null;`

  This is the outcome on which this player focuses their betting. For now, we'll build this Outcome the hard way. In the long run, we should get this from some souce (`Game`, `Wheel` or `Table`) using a well-known bet name.

- `Table table ;`

  Used to place individual bets.

### Constructors

- `PlayerStub(Table aTable);`

  Constructs the `Player` with a specific table for placing bets. This also creates the "black" `Outcome`. This is saved in the `black` variable for use in creating bets.

### Methods

- `void placeBets();`

  Updates the `Table` with the various bets. This version creates a `Bet` instance from the `black` `Outcome`. It uses `Table` `placeBet` to place that bet.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The amount of money won is available via `theBet` `winAmount`.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser.

## Roulette Game Class

`Game` manages the sequence of actions that defines the game of Roulette. This includes notifying the `Player` to place bets, spinning the `Wheel` and resolving the `Bets` actually present on the `Table`.

### Fields

- `Wheel theWheel ;`

Contains the wheel that returns a randomly selected `Bin` of `Outcomes`.

- `Table theTable ;`

  Contains the bets placed by the player.

- `Player thePlayer ;`

  Places bets on the table.

### Constructors

- We based the Roulette constructor on a design that allows any of the fields to be replaced. This is the **Strategy** design pattern. Each of these objects is a replaceable strategy, and can be changed by the client that uses this game.

  Additionally, we specifically do not include the `Player` instance in the constructor. The `Game` exists independently of any particular `Player`, and we defer binding the `Player` and `Game` until we are gathering statistical samples.

  ```
  Game(Wheel aWheel,
       Table aTable);
  ```

  Constructs a new `Game`, using a given `Wheel` and `Table`.

### Methods

- `void cycle(Player aPlayer);`

  This will execute a single cycle of play with a given `Player`. It will call `thePlayer` `placeBets` to get bets. It will call `theWheel` `next` to get the next winning `Bin`. It will then call `theTable`'s `bets` to get an `Iterator` over the `Bets`. Stepping through this `Iterator` returns the individual `Bet` objects. If the winning `Bin` contains the `Outcome`, call the `thePlayer` `win`, otherwise call the `thePlayer` `lose`.

## Questions and Answers

Q: Why are Table and Wheel part of the constructor while Player is given as part of the cycle method?
Q: Why do we have to include the odds with the Outcome? This pairing makes it difficult to create an Outcome from scratch.

**Q:** Why are `Table` and `Wheel` part of the constructor while `Player` is given as part of the `cycle` method?

**A:** We are making a subtle distinction between the casino table game (a Roulette table, wheel, plus casino staff to support it) and having a player step up to the table and play the game. The game exists without any particular player. By setting up our classes to parallel the physical entities, we give ourselves the flexibility to have multiple players without a significant rewrite. We allow ourselves to support multiple concurrent players or multiple simulations each using a different player object.

Also, as we look forward to the structure of the future simulation, we note that the game objects are largely fixed, but there will be a parade of variations on the player. We would like a main program that simplifies inserting a new player subclass with minimal disruption.

**Q:** Why do we have to include the odds with the `Outcome`? This pairing makes it difficult to create an `Outcome` from scratch.

**A:** The odds are an essential ingredient in the `Outcome`. It turns out that we want a short-hand name for each Outcome. We have three ways to provide a short name.

- A variable name. Since each variable is owned by a specific class instance, we need to allocate this to some class. The `Wheel` or the `BinBuilder` make the most sense for owning this variable.
- A key in a mapping. In this case, we need to allocate the mapping to some class. Again, the `Wheel` or `BinBuilder` make the most sense for owning the mapping.
- A method which returns the `Outcome`. The method can use a fixed variable or can get a value from a mapping.

## Deliverables

There are three deliverables for this exercise. The stub does not need documentation, but the other classes do need complete Javadoc or Python docstrings.

- The `Passenger57` class. We will rework this design later. This class always places a bet on Black. Since this is simply used to test `Game`, it doesn't deserve a very sophisticated unit test of its own. It will be replaced in a future exercise.
- The `RouletteGame` class.
- A class which performs a demonstration of the `Game` class. This demo program creates the `Wheel`, the stub `Passenger57` and the `Table`. It creates the `Game` object and cycles a few times. Note that the `Wheel` returns random results, making a formal test rather difficult. We'll address this testability issue in the next chapter.

# Chapter 11. Review of Testability

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Deliverables

This chapter presents some design rework and implementation rework for testability purposes. While testability is very important, new programmers can be slowed to a crawl by the mechanics of building test drivers and test cases. We prefer to emphasize the basic design considerations first, and address testability as a feature to be added to a working class.

Additionally, we'll address some issues in construction of class instances and an idealized structure for the main procedure.

## Overview

We have been studiously ignoring an elephant standing in the saloon. This is the problem of testing an application that includes a random number generator (RNG). There are two questions raised:

1. How can we develop formalized unit tests when we can't predict the random outcomes? This is a serious testability issue in randomized simulations. This question also arises when considering interactive applications, particularly for performance tests of web applications where requests are received at random intervals.

2. Are the numbers really random? This is a more subtle issue, and is only relevant for more serious applications. Cryptographic, statistical or actuarial applications may care about the randomness of random numbers. This is a large subject, and well beyond the scope of this book. We'll just assume that our random number generator is good enough.

We'll address this first issue by developing some scaffolding that permits controlled testing. There are three approaches to replacing the random behavior with something more controlled. One approach is to subclass `Wheel` to create a more testable version without the random number generator. An alternative to changing wheel is to define a subclass of `java.util.Random` (or Python's `random`) that isn't actually random. A third approach is to record the sequence of random numbers actually generated from a particular seed value and use this to define the exected test results. For more information on this third alternative, see On Random Numbers.

### On Random Numbers

Random numbers aren't actually “random”. Since they are generated by an algorithm, they are sometimes called *pseudo-random*. The distinction is important because pseudo-random numbers are generated in a fixed sequence from a given *seed value*. Computing the next value in the sequence involves a simple calculation that is expected to overflow the available number of bits of precision leaving apparently random bits as the next value. This leads to results which, while predictable, are arbitrary enough that they pass rigorous statistical tests and are indistinguishable from data created by random processes.

We can make an application less predictable by choosing a very hard to predict seed value. One popular choice for the seed is the system clock. In some operating systems a special device is available for producing random seed values. In Linux this is typically `/dev/random`.

Conversely, we can make an application more predictable by setting a fixed seed value and noting the sequence of numbers generated. We can write a short demonstration program to see the effect of setting a fixed seed. This will also give us a set of predictable answers for unit testing.

We'll need to build and execute a program that reveals the fixed sequence of spins that are created by the non-random number generator.

**Procedure 11.1. Revealing the Non-Random Spins**

1. Create an instance of `NonRandom` or `Random`. Set the seed of the this random number generator to a fixed value, for example, `3`.
2. Create an instance of `Wheel` using this non-random number generator.
3. Call the `next` method of `Wheel` six times, and print the winning `Bin` instances. This sequence will always be the result for a seed value of `3`.

This discovery procedure will give you the results needed to create unit tests for `Wheel` and anything that uses it, for example, `Game`.

Good testability is achieved when there are no changes to the target software. For this reason, we don't want to have two versions of `Wheel`, one for testing and one for normal operations.

Instead of having two versions of Wheel, it's slightly better to have a random number generator that creates a known sequence with which we can test. To get this known sequence, we have a choice between creating a non-random subclass of `java.util.Random` or controlling the seed for the random number generator used by `Wheel`. Both will produce a known sequence of non-random values.

One consequence of either of these decisions is that we have to make the random number generator in `Wheel` more visible. Our favorite approach to making something more visible is to assign an object through an official interface method or possible as part of the constructor. In the case of `Wheel`, we'd jave our overall simulation or test assign an appropriate number generating object to the instance of `Wheel` rather than have `Wheel` privately create a generator.

When we are doing testing, we can associate a `Wheel` with an instance of `NonRandom`, or an instance of `Random` initialized with a known seed. For actual use, we can then associate a `Wheel` with an instance of `java.util.Random`; this will either use the RNG's default constructor to assure unpredictability.

We'll need an additional constructor for `Wheel` that allows us to provide an appropriately initialized generator. Our current constructor secretly creates an instance of a RNG, using the RNG's default constructor. We'll need an additional method that provides an RNG, already initialized with an appropriate value.

For Python programmers, this is handled as a second parameter with a default value.

Note that, consistent with our principle of deferred binding, we don't have to choose exactly which implementation we will use. By allowing `Wheel` to take either an instance of `Random` initialized with a given seed or an instance of a new subclass, `NonRandom`, we have given ourselves the flexibility to choose either implementation. We'll provide specifications for `NonRandom`, but using a fixed seed for `Random` is seen by some as simpler.

### Python Subclass Design

Because of the late binding in Python, and the lack of compile-time type checking, we don't have to use strict subclass inheritance to replace the Python random number generator with our own non-random number generator. We could cheat and provide a class with just the minimal interface that our application requires.

While legal, we prefer not to bypass the inheritance tree in Python. We find that applications are much easier to maintain if reasonable care is taken to assure that the classes and interfaces are matched up as precisely as possible. In this case, we'll want to make our non-random generator a strict subclass of the `Random` class.

## Questions and Answers

Q: Why are we making the random number generator more visible? Isn't object design about encapsulation?
Q: If setting the seed works so well, why make a non-random subclass?

**Q:** Why are we making the random number generator more visible? Isn't object design about encapsulation?

**A:** Encapsulation isn't the same thing as “information hiding”. For some people, the information hiding concept can be a useful way to begin to learn about encapsulation. However, information hiding is misleading because it is often taken to exremes. In this case, we want to encapsulate the bins of the wheel and the procedure for selecting the winning bin into a single object. However, the exact random-number generator (RNG) is a separate component, allowing us to bind any suitable RNG.

Consider the situation where we are generating random numbers for a cryptographic application. In this case, the built-in random number generator may not be random enough. In this case, we may have a third-party Super-Random-Generator that should replace the built-in generator. We would prefer to minimize the changes required to introduce this new class.

Our initial design has isolated the changes to the `Wheel`, but required us to change the constructor. Since we are changing the source code for a class, we must to unit test that change. Further, we are also obligated unit test all of the classes that depend on this class. Changing the source for a class deep within the application forces us to endure the consequence of retesting every class that depends on this deeply buried class. This is too much work to simply replace one object with another.

We do, however, have an alternative. We can change the top-level `main` method, altering the concrete object instances that compose the working application. By making the change at the top of the application, we don't need to change a deeply buried class and unit test all the classes that depend on the changed class. Instead, we are simply choosing among objects with the same superclass or interface.

This is why we feel that constructors should be made very visible using the various design patterns for **Factories** and **Builders**. Further, we look at the main method as a kind of master **Builder** that assembles the objects that comprise the current execution of our application.

See our Why does the `Game` class run the sequence of steps? Isn't that the responsibility of some “main program?” FAQ for more on this subject.

Looking ahead, we will have additional notes on this topic as we add the `SevenReds` subclass of `Player`.

**Q:** If setting the seed works so well, why make a non-random subclass?

**A:** While setting the seed is an excellent method for setting up a unit test, not everyone is comfortable with random number generators. The presence of an arbitrary but predictable sequence of values looks too much like luck for some *Quality Assurance* (QA) managers. While the algorithms for both Python and Java random number generators are published and well-understood, this isn't always sufficiently clear and convincing for non-mathematicians. It's often seems simpler to build a non-random subclass than to control the existing class.

From another point of view, creating a subclass of a built-in class is a necessary skill. The random number generators are easy classes to extend. Extending the abstract collection classes is also a very useful skill, but somewhat more complex than extending the random number generator.

## Design

We'll present the design modification for `Wheel` first. This will be followed by design information for `NonRandom` in both Java and Python.

### Wheel Rework

`Wheel` contains the 38 individual bins on a Roulette wheel, plus a random number generator. It can select a `Bin` at random, simulating a spin of the Roulette wheel.

Note that we will be rewriting these methods to change their implementation. The definitions of the methods don't change, but the implementations can (and do) change. This is the real strength of OO design. Once we have a well-defined interface (defined by the public methods and attributes), we are free to change the implementation as necessary.

This kind of rework — making a fundamental change to the implementation without touching the interface — is essential to successful OO programming.

#### Fields

- Java: `java.util.Vector bins = new Vector( 38 );`

  Python: `bins = 38*[None]`

  Contains the individual `Bin` instances.

- Java: `java.util.Random rng = new java.util.Random();`

Python: `rng = random.Random()`

Generates the next random number, used to select a `Bin` from the `bins` collection.

### Constructors

- `Wheel();`

  This will also create a new random number generator instance. It will then use the other constructor to do the rest of the initialization.

- `Wheel(Random rng);`

  Creates a new wheel with 38 empty `Bins`. It will use the given random number generator instance.

### Methods

-
  ```
  addOutcome(int number,
             Outcome outcome);
  ```

  Adds the given `Outcome` to the `Bin` with the given number.

- `next();`

  Generates a random number between 0 and 37, and returns the randomly selected `Bin`.

  Java: Be sure to note that the `java.util.Random` `nextInt` method uses the size of the `bins` collection to return values from 0 to the size of the collection. Typically there are 38 values, numbered from 0 to 37.

  Python: the `choice` function will select one of the available `Bins` from the `bins` list.

- `Bin getBin(int aBin);`

  Returns the given `Bin` from the internal collection.

## Java NonRandom Class

We need a controlled kind of random number generation for testing purposes. We'll define a class `NonRandom` that extends `java.util.Random`, but provides a more testable sequence of values. One approach is to simply count through a range of integer vales.

The API documentation gives us the advice that the `protected int next(int bits);` generates the next pseudorandom number. It says that any subclass should override this, as this is used by all other methods.

### Fields

- `int value = 0;`

  This will be used to count through the non-random sequence of values.

### Constructors

- `NonRandom();`

  This is the default constructor, and will initialize `value` to zero.

- `NonRandom(long seed);`

  This constructor ignores the seed value. It initializes `value` to zero.

### Methods

- `next(int bits);`

  This method is the heart of the generator. In our case, we simply add one to `value` and return the new value. This provides a predicable sequence of values.

## Python NonRandom Class

`Nonrandom` module provides the same interface as `random.Random`, but merely counts through a range of integer vales.

The API documentation gives us the advice that a subclass should override the `random()`, `seed()`, `getstate()`, `setstate()` and `jumpahead()` methods. However, we can safely ignore all but the `random()` method itself.

### Fields

- `value = 0`

  This will be used to count through the non-random sequence of values.

### Constructors

- `def NonRandom(self):`

  This is the default constructor, and will initialize `value` to zero.

- `def NonRandom(self, seed):`

  This constructor ignores the seed value. It initializes `value` to zero.

### Methods

- `def random(self):`

  This method is the heart of the generator. In our case, we simply add 1 to the value and return (value % 38)/38.0 . This provides a predicable sequence of values that is suitable for our testing.

  The return value does two things. First, it computest the remainder when the value is divided by 38. This will be a value from 0 to 37. Then it divides this by 38 to return a floating-point number in the half-open range [0.0, 1.0), as required by the API. This means that 0.0 is included, but 1.0 is not included.

## Deliverables

There are five deliverables for this exercise. All of these deliverables need appropriate Javadoc comments or Python docstrings.

- A modified design for `Wheel`. This add the second constructor that allows us to pass in a particular random number generator to `Wheel`. Also, there will be considerable rewriting of the original Wheel.
- The `NonRandom` class.
- A demonstration program of the new wheel and the `NonRandom` class (or the `Random` class with a known seed) that shows the results of a dozen spins of the non-random wheel. In the case of seeding `Random`, the spins while be in an arbitrary order, but will be the same each time the program is run.
- Revised unit tests for `Wheel` based on the fixed sequence of responses from the non-random number generator.
- Revised unit tests for Game based on this revised version of `Wheel` based on the fixed sequence of responses from the non-random number generator.

# Chapter 12. Player Class

### Table of Contents

The variations on `Player`, all of which reflect different betting strategies, is the heart of this application. In Chapter 10, *Roulette Game Class*, we roughed out a stub class for `Player`. In this chapter, we will complete that design. We will also expand on it to implement the Matingale betting strategy.

## Overview

We have now built enough infrastructure that we can begin to add a variety of players and see how their betting strategies work. Each player is betting algorithm that we will evaluate by looking at the player's stake to see how much they win, and how long they play before they run out of time or go broke.

The `Player` has the responsibility to create bets and manage the amount of their stake. To create bets, the player must create legal bets from known `Outcomes` and stay within table limits. To manage their stake, the player must deduct money when creating a bet, accept winnings or pushes, report on the current value of the stake, and leave the table when they are out of money.

We have an interface that was roughed out as part of the design of `Game` and `Table`. In designing `Game`, we put a `placeBets` method in `Player` to place all bets. We expected the `Player` to create `Bets` and use the `placeBet` method of `Table` class to save all of the individual `Bets`.

In an earlier exercise, we built a stub version of `Player` in order to test `Game`. See Passenger57 Class. When we finish creating the final superclass, `Player`, we will also revise our `Passenger57` to be a subclass of `Player`, and rerun our unit tests to be sure that our more complete design still handles the basic test cases correctly.

Our objective is to have a new abstract class, `Player`, with two new concrete subclasses: a revision to `Passenger57` and a new player that follows the Martingale betting system.

We'll defer some of the design required to collect detailed measurements for statistical analysis. In this first release, we'll simply place bets.

There are four design issues tied up in `Player`: tracking stake, keeping within table limits, leaving the table, and creating bets. We'll tackle them in separate subsections.

**Tracking the Stake.** One of the more important features we need to add to `Player` are the methods to track the player's stake. The initial value of the stake is the player's budget. There are two significant changes to the stake.

- Each bet placed will deduct the bet amount from the `Player`'s stake. We are stopped from placing bets when our stake is less than the table minimum.
- Each win will credit the stake. The `Outcome` will compute this amount for us.
- Additionally, a push will put the original bet amount back. This is a kind of win with no odds applied.

We'll have to design an interface that will create `Bets`, reducing the stake. and will be used by `Game` to notify the `Player` of the amount won.

Additionally, we will need a method to reset the stake to the starting amount. This will be used as part of data collection for the overall simulation.

**Table Limits.** Once we have our superclass, we can then define the `Martingale` player as a subclass. This player doubles their bet on every loss, and resets their bet to a base amount on every win. In the event of a long sequence of losses, this player will have their bets rejected as over the table limit. This raises the question of how the table limit is represented and how conformance with the table limit is assured. We put a preliminary design in place in Roulette Table Class. There are several places where we could isolate this responsibility.

1. The `Player` stops placing bets when they are over the `Table` limit. In this case, we will be delegating responsibility to the `Player` hierarchy. In a casino, a sign is posted on the table, and both players and casino staff enforce this rule. This can be modeled by providing a method in `Table` that simply returns the table limit for use by the `Player` to keep bets within the limit.

2. The `Table` provides a "valid bet" method. This reflects a more general situation where a stateful game has bets that change. In Craps, for example, most bets cannot be placed until a point is established.

3. The `Table` throws an "illegal bet" exception when an illegal bet is placed. While permissable, this kind of use for exceptions pushes the envelope on clarity and simplicity. One viewpoint is that exceptions should be reserved for situations that are truly unexpected. In this case, we expect to run into the table limit situation fairly often using Martigale betting.

We recommend the second choice: adding a `isValid` method to the `Table` class. This has the consequence of allocating responsibility to `Table`, and permits us to have more advanced games where some bets are not allowed during some game states. It also obligates `Player` to validate each bet with the `Table`. It also means that at some point, the player may be unable to place a legal bet.

We could also implement this by adding to the responsibilities of the existing `placeBet` method. For example, we could return `true` if the bet was accepted, and `false` if the bet violated the limits or other game state rules. We prefer to isolate responsibility and create a second method rather than pile too much into a single method.

**Leaving the Table.** In enumerating the consequences of checking for legal bets, we also uncovered the issue of the `Player` leaving the game. We can identify a number of possible reasons for leaving: out of money, out of time, won enough, and unwilling to place a legal bet. Since this decision is private to the `Player`, we need a way of alerting the `Game` that the `Player` is finished placing bets.

There are three mechanisms for alerting the `Game` that the `Player` is finished placing bets.

1. Expand the responsibilities of the `placeBets` to also indicate if the player wishes to continue or is withdrawing from the game. While most table games require bets on each round, it is possible to step up to a table and watch play before placing a bet. This is one classic strategy for winning at blackjack: one player sits at the table, placing small bets and counting cards, while a confederate places large bets only when the deck is favorable. We really have three player conditions: watching, betting and finished playing. It becomes complex trying to bundle all this extra responsibility into the `placeBets` method.

2. Add another method to `Player` that the `Game` can use to determine if the `Player` will continue or stop playing. This can be used for a player who is placing no bets while waiting; for example, a player who is waiting for the Roulette wheel to spin red seven times in a row before betting on black.

3. The `Player` can throw an exception when they are done playing. This is an exceptional situation: it occurs exactly once in each simulation. However, it is a well-defined condition, and doesn't deserve to be called “exceptional”. It is merely a terminating condition for the game.

We recommend adding a method to `Player` to indicate when `Player` is done playing. This gives the most flexibility, and it permits `Game` to cycle until the player withdraws from the game.

A consequence of this decision is to rework the `Game` class to allow the player to exit. This is relatively small change to interrogate the `Player` before asking the player to place bets.

### Note

In this case, these were situations which we didn't discover during the initial design. It helped to have some experience with the classes in order to determine the proper allocation of responsibilities. While design walkthroughs are helpful, an alternative is a “prototype”, a piece of software that is incomplete and can be disposed of. The earlier exercise created a version of `Game` that was incomplete, and a version of `PlayerStub` that will have to be disposed of.

**Creating Bets from Outcomes.** Generally, a `Player` will have a few `Outcomes` on which they are betting. Many systems are similar to the Martingale system, and place bets on only one of the `Outcomes`. These `Outcome` objects are usually created during player initialization. From these `Outcomes`, the `Player` can create the individual `Bet` instances based on their betting strategy.

## Design

We'll design the base class of `Player` and a specific subclass, `Martingale`. This will give us a working player that we can test with.

### Player superclass

`Player` places bets in Roulette. This an abstract class, with no actual body for the `placeBets` method. However, this class does implement the basic `win` method used by all subclasses.

#### Fields

- `int stake ;`

  The player's current stake. Initialized to the player's starting budget.

- `int roundsToGo ;`

  The number of rounds left to play. Initialized by the overall simulation control to the maximum number of rounds to play. In Roulette, this is spins. In Craps, this is the number of throws of the dice, which may be a large number of quick games or a small number of long-running games. In Craps, this is the number of cards played, which may be large number of hands or small number of multi-card hands.

- `Table table ;`

  Used to place individual `Bet`s.

### Constructors

- `Player(Table aTable);`

  Constructs the `Player` with a specific `Table` for placing `Bet`s.

### Methods

- `boolean playing();`

  Returns `true` while the player is still active.

- `void placeBets();`

  Updates the `Table` with the various `Bet`s.

  When designing the `Table`, we decided that we needed to deduct the amount of a bet from the stake when the bet is created. See the Table Overview for more information.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The amount of money won is available via `theBet winAmount`.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser. Note that the amount was already deducted from the stake when the bet was created.

## Martingale Player

`Martingale` is a `Player` who places bets in Roulette. This player doubles their bet on every loss and resets their bet to a base amount on each win.

### Fields

- `int lossCount ;`

  The number of losses. This is the number of times to double the bet.

- `int betMultiple ;`

The the bet multiplier, based on the number of losses. This starts at 1, and is reset to 1 on each win. It is doubled in each loss. This is always equal to $2^{lossCount}$.

**Methods**

- `void placeBets();`

  Updates the `Table` with a bet on black. The amount bet is $2^{lossCount}$, which is the value of `betMultiple`.

- `void win(Bet theBet);`

  Uses the superclass `win` method to update the stake with an amount won. This method then resets `lossCount` to zero, and resets `betMultiple` to `1`.

- `void lose(Bet theBet);`

  Increments `lossCount` by `1` and doubles `betMultiple`.

## Deliverables

There are six deliverables for this exercise. The new classes must have Javadoc comments or Python docstrings.

- The `Player` abstract superclass. Since this class doesn't have a body for the `placeBets`, it can't be unit tested directly.
- A revised `Passenger57` class. This version will be a proper subclass of `Player`, but still place bets on black until the stake is exhausted. The existing unit test for `Passenger57` should continue to work correctly after these changes.
- The `Martingale` subclass of `Player`.
- A unit test class for `Martingale`. This test should synthesize a fixed list of `Outcomes`, `Bins`, and calls a `Martingale` instance with various sequences of reds and blacks to assure that the bet doubles appropriately on each loss, and is reset on each win.
- A revised `Game` class. This will check the player's `playing` method before calling `placeBets`, and do nothing if the player withdraws. It will also call the player's `win` and `lose` methods for winning and losing bets.
- A unit test class for the revised `Game` class. Using a non-random generator for `Wheel`, this should be able to confirm correct operation of the `Game` for a number of bets.

# Chapter 13. Overall Simulation Control

### Table of Contents

This section starts to address the overall “main program” that pulls the various classes together to create a finished application. Additionally, we'll also address some issues in how Java handles collections of primitive data types like integers.

## Overview

We can now use our application to generate some more usable results. We can perform a number of simulation runs and evaluate the long-term prospects for the Martingale betting system. We want to know a few things about the game:

- How long can we play with a given budget? In other words, how many spins before we've lost our stake.
- How much we can realistically hope to win? How large a streak can we hope for? How far ahead can we hope to get before we should quit?

The `Simulator` will be an active class with a number of responsibilities

- Create the `Wheel`, `Table` and `Game` objects.
- Simulate a number of sessions (typically 100), saving the maximum stake and length of each session.
- For each session: initialize the `Player` and `Game`, cycle the game a number of times, collect the size of the `Player`'s stake after each cycle.
- Write a final summary of the results.

At this point, we'll need for formalize some definitions, just to be crystal clear on the responisbility allocation.

### Simulation Terms

cycle

A single cycle of betting and bet resolution. This depends on a single random event: a spin of the wheel or a throw of the dice. Also known as a round of play.

session

One or more cycles. The session begins with a player having their full stake. A session ends when the play elects to leave or can no longer participate. A player may elect to leave because of elapsed time (typically 250 cycles), or they have won a statistically significant amount. A player can no longer participate when their stake is too small to make the minimum bet for the table.

game

Some games have intermediate groupings of events between an individual cycles and an entire session. Blackjack has *hands*, where a number of player decisions and a number of random events contribute to the payoff. Craps has a *game*, which starts with the dice roll when the point is *off*, and ends when the point is made or the shooter gets *Craps*; consequently, any number of individual dice rolls can make up a game. Some bets are placed on the overall game, while others are placed on individual dice rolls.

The sequence of operations for the simulator looks like this.

**Procedure 13.1. Controlling the Simulation**

1. **Empty List of Maxima.** Create an empty maxima list. This is the maximum stake at the end of each session.

2. **Empty List of Durations.** Create an empty durations list. This is the duration of each session, measured in the number of cycles of play before the player withdrew or ran out of money.

3. **For All Sessions.** For each of 100 sessions:

   a. **Empty List of Stake Details.** Create an empty list to hold the history of stake values for this session. This is raw data that we will summarize into two metrics for the session: maximum stake and duration. We could also have two simple variables to record the maximum stake and count the number of spins for the duratioon. However, the list allows us to gather other statistics, like maximum win or maximum loss.

   b. **While The Player Is Active**

      i. **One Cycle.** Play one cycle of the game. See the definition in Roulette Game Class.

      ii. **Save Detail.** Save the player's current stake in the list of stake values for this session. The alternative is to update the maximum to be the larger of the current stake and the maximum, and increment the duration.

   c. **Get Maximum.** Get the maximum stake from the list of stake values. Save the maximum stake metric in the maxima list.

   d. **Get Duration.** Get the length of the list of stake values. Save the duration metric in the durations list.

4. **Statistical Description of Maxima.** Compute the average and standard deviation of the values in the

maxima list.

5. **Statistical Description of Durations.** Compute the average and standard deviation of values in the durations list.

Both this overall `Simulator` and the `Game` collaborate with the `Player`. The `Simulator`'s collaboration, however, initalizes the `Player` and then monitor's the changes to the `Player`'s stake. We have to design two interfaces for this collaboration.

**Player Initialization.** The `Simulator` will initialize a `Player` for 250 cycles of play, assuming about one cycle each minute, and about four hours of patience. We will also initialize the player with a generous budget of the table limit, 100 betting units. For a $10 table, this is $1,000 bankroll.

Currently, the `Player` class is designed to play one session and stop when their duration is reached or their stake is reduced to zero. We have two alternatives for reinitializing the `Player` at the beginning of each session.

1. Provide some *setters* that allow a client class like this overall simulator control to reset the `stake` and `roundsToGo` values of a `Player`.

2. Provide a **Factory** that allows a client class to create new, freshly initialized instances of `Player`.

While the first solution is quite simple, there are some advantages to creating a `PlayerFactory`. If we create an **Abstract Factory**, we have a single place that creates all `Players`. Further, when we add new player subclasses, we introduce these new subclasses by creating a new subclass of the factory. In this case, however, only the main program creates instances of `Player`, reducing the value of the factory. While design of the factory is a good exercise, we can scrape by with adding setter methods to the `Player` class.

**Player Interrogation.** The `Simulator` will interrogate the `Player` after each cycle and capture the current stake. An easy way to manage this detailed data is to create a `List` that contains the stake at the end of each cycle. The length of this list and the maximum value in this list are the two metrics the `Simulator` gathers for each session.

Our list of maxima and durations are created sequentially during the session and summarized sequentially at the end of the session. A Java `LinkedList` will do everything we need. For a deeper discussion on the alternatives available in the collections framework, see Java Collections.

**Statistical Summary.** The `Simulator` will interrogate the `Player` after each cycle and capture the current stake. We don't want the sequence of stakes for each cycle, however, we want a summary of all the cycles in the session. We can save the length of the sequence as well as the maximum of the sequence to determine these two aggregate performance parameters for each session. Our objective is to run several session simulations to get averages and a standard deviations for duration and maximum stake. This means that the `Simulator` needs to retain these statistical samples. We will defer the detailed design of the statistical processing, and simply keep the duration and maximum values in Lists for this first round of design.

## Design

`Simulator` exercises the Roulette simulation with a given `Player` placing bets. It reports raw statistics on a number of sessions of play.

### Handling Lists of Values in Java

Python programmers can skip this tip because Python can use lists of simple integer values. Using the map and reduce functions, Python programmers can implement handy statistical functions.

Java programmers can't easily accumulate a `List` of int values. This is because a primitive int value is not an object. The usual solution is to make an `Integer` value from the int, and put the `Integer` object into the list.

When getting values back out of the list, there is a two-step dance: cast the item in the list to be an `Integer`, then get the int value of that object. The following examples show this as two steps.

**Example 13.1. Java Explicit Iteration Through a List of Integers**

```
Integer tempMax = (Integer)iterator.next()) ❶
int aMax = tempMax.intValue(); ❷
```

❶ This gets the next `Object` from the `iterator`, and casts this to be an `Integer`.
❷ This gets the primitive int value from the `Integer` object.

Some people prefer the following. It is short, a little confusing to first-time programmers, but a common idiom.

**Example 13.2. Java Compressed Iteration Through a List of Integers**

```
int aMax = ((Integer)iterator.next()).intValue();
```

## Fields

- `int initDuration = 250;`

  The duration value to use when initializing a `Player` for a session.

- `int initStake = 100;`

  The stake value to use when initializing a `Player` for a session.

- `int samples ;`

  The number of game cycles to simulate. A default value of 50 makes sense.

- `List durations ;`

  A list of lengths of time the `Player` remained in the game. Each session of play producrs a duration metric, which are collected into this list.

- `List maxima ;`

  A list of maximum stakes for each `Player`. Each session of play producrs a maximum stake metric, which are collected into this list.

- `Player thePlayer ;`

  The betting strategy we are simulating.

- `Game theGame ;`

  The casino game we are simulating.

### Constructors

-
  ```
  Simulator(Game game,
            Player player);
  ```

  Saves the `Player` and `Game` instances so we can gather statistics on the performance of the player's betting strategy.

### Methods

- `List session();`

  Executes a single game session. The `Player` is initialized with their initial stake and initial cycles to go. An empty `List` of stake values is created. The session loop executes until the `Player playing` returns false. This loop executes the `Game cycle`; then it gets the stake from the `Player` and appends this amount to the `List` of stake values. The `List` of individual stake values is returned as the result of the session of play.

- `gather();`

  Executes the number of games sessions in `samples`. Each game session returns a `List` of stake values. When the session is over (either the play reached their time limit or their stake was spent), then the length of the session `List` and the maximum value in the session `List` are the resulting duration and maximum metrics. These two metrics are appended to the `durations` list and the `maxima` list.

  A client class will either display the durations and maxima raw metrics or produce statistical summaries.

## Deliverables

There are five deliverables for this exercise. Each of these classes needs complete Javadoc or Python docstring comments.

- Revision to the `Player` class to add two new methods: one will set the `stake` and the other will set the `roundsToGo`.

  ```
  void setStake(int initStake);
  void setRounds(int initRounds);
  ```

- The `Simulator` class.
- The expected outcomes from the non-random wheel can be rather complex to predict. Because of this, one of the deliverables is a demonstration program that enumerates the actual sequence of non-random spins. From this we can derive the sequence of wins and losses, and the sequence of `Player` bets. This will allow us to predict the final outcome from a single session.
- A unit test of the `Simulator` class that uses the non-random generator to produce the predictable sequence of spins and bets.
- A main application class that creates the necessary objects, runs the `Simulator`'s `gather` method, and writes the available outputs to `System.out` In this case, it will print the list of maxima, and the list of session lengths. This raw data can be redirected to a file, loaded into a spreadsheet and analyzed.

# Chapter 14. Player SevenReds

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This section introduces an additional specialization of the Martingale strategy. Additionally, we'll also address some issues in how an overall application is composed of individual class instances. Adding this new subclass should be a small change to the main application class.

## Overview

The SevenReds player waits for seven red wins in a row before betting black. This is a subclass of `Player`. We can create a subclass of our main `Simulator` to use this new `SevenReds` class.

We note that our previous players (`Passenger57` and `Martingale`) are stateless: they place the same bets over and over until they are cleaned out or their playing session ends. This `SevenReds` player has two states: waiting and betting. In the waiting state, they are simply counting the number of reds. In the betting state, they have seen seven reds and are now playing the Martingale system on black. We will defer serious analysis of this *stateful* betting until some of the more sophisticated subclasses of `Player`. For now, we will simply use an integer to count the number of reds.

Currently, the player is not informed of the final outcome unless they place a bet. We designed the `Game` to evaluate the `Bet` instances and notify the `Player` of just their `Bets` that were wins or losses. We will need to add a method to `Player` to be given the overall list of winning `Outcomes` even when the `Player` has not placed a bet.

Once we have updated the design of `Game` to notify `Player`, we can add the new `SevenReds` class. Note that we are can intoduce each new betting strategy via creation of new subclasses. A relatively straightforward update to our simulation main program allows us to use these new subclasses. The previously working subclasses are left in place, allowing graceful evolution by adding features with minimal rework of existing classes.

In addition to waiting for the wheel to spin seven reds, we will also follow the Martingale betting system to track our wins and losses, assuring that a single win will recoup all of our losses. This makes `SevenReds` a further specialization of `Martingale`. We will be using the basic features of `Martingale`, but doing additional processing to determine if we should place a bet or not.

Introducing a new subclass should be done by upgrading the main program. See Soapbox on Composition for comments on the ideal structure for a main program. Additionally, see our Why does the `Game` class run the sequence of steps? Isn't that the responsibility of some “main program?” FAQ entry and Why are we making the random number generator more visible? Isn't object design about encapsulation? FAQ entry for more discussion.

## Soapbox on Composition

Generally, a solution is composed of a number of objects. However, the consequences of this are often misunderstood. Since the solution is a composition of objects, it falls on the main method to do just the composition and nothing more.

Our ideal main program creates and composes the working set of objects. In this case, it should decode the command-line parameters, and use this information to create and initialize the simulation objects, then start the processing. For these simple exercises, however, we're omitting the parsing of command-line parameters, and simply creating the necessary objects directly.

Our main program should, therefore, look something like the following:

**Example 14.1. Java Main Program**

```
Random theRNG= new Random(); ❶
Wheel theWheel= new Wheel( theRNG );
Table theTable= new Table();
Game theGame= new Game( theWheel, theTable );
Player thePlayer= new SevenReds( table ); ❷
Simulator sim= new Simulator( theGame, thePlayer );
sim.gather(); ❸
```

❶ This can also use NonRandom. The idea is that we build up the functionality of Wheel by composition. We compose the wheel of the bins plus the number generator.

❷ This can also be Martingale or Passenger57 (who always bets on black). Again, we have assembled the final simulation by composition of a Wheel (and its generator), the Table and the specific Player algorithm.

❸ This is the actual work of the application, done by the `Simulator`, using the `Game` and `Player` objects built by main.

In many instances, the construction of objects is not done directly by the main method. Instead, the main method will construct a base group of **Abstract Factory** and **Builder** objects. Given these objects and the command-line parameters, the application objects can be built. The application objects then collaborate to perform the required functions.

## Design

`SevenReds` is a `Martingale` player who places bets in Roulette. This player waits until the wheel has spun red seven times in a row before betting black.

### Fields

- `int redCount ;`

  The number of reds yet to go. This starts at `7`, is reset to `7` on each non-red outcome, and decrements by `1` on each red outcome.

- Note that we inherit `betMultiple`. This is initially `1`, doubles with each loss and is reset to one on each win.

### Methods

- `void placeBets();`

  If `redCount` is zero, this places a bet on black, using the bet multiplier.

- `void winners(Bin outcomes);`

  This is notification from the `Game` of all the winning outcomes. If this vector includes red, `redCount` is decremented. Otherwise, `redCount` is reset to `7`.

## Deliverables

There are five deliverables from this exercise. The new classes will require complete Javadoc comments or Python docstrings.

- A revision to the `Player` to add the following method. The superclass version doesn't do anything with this information. Some subclasses, however, will process this.

  ```
  void winners(Bin outcomes);
  ```

- The `SevenReds` subclass of `Player`.
- A revision to the `Game` class. This will call the `winners` with the winning `Bin` instance before paying off the bets.
- A unit test of the `SevenReds` class. This test should synthesize a fixed list of `Outcome`s, `Bin`s, and calls a `SevenReds` instance with various sequences of reds and blacks. One test cases can assure that no bet is placed until 7 reds have been seen. Another test case can assure that the bets double (following the Martingale betting strategy) on each loss.
- A main application class that creates the necessary objects, runs the `Simulator`'s `gather` method, and writes the available outputs to `System.out` In this case, it will simply print the list of maxima, and the list of session lengths.

# Chapter 15. Statistical Measures

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This section presents two ordinary statistical algorithms: mean and standard deviation. In one sense, this section could be treated as optional. Instead of having the simulator present useful summary statistics, raw data can be put into a spreadsheet for creating the statistics.

However, the process of designing these statistical processing classes is very interesting. This chapter examines some ways to add features to the built-in collection classes.

## Overview

Currently, the `Simulator` class collects two `List`s. One has the length of a session, the other has the maximum stake during a session. We need to create some descriptive statistics to summarize these stakes and session lengths.

### On Statistics

In principle, we could apply basic probability theory to predict the statistics generated by this simulation. Indeed, some of the statistics we are gathering are almost matters of definition, rather than actual unknown data. We are, however, much more interested in the development of the software than we are in applying probability theory to a relatively simple casino game. As a consequence, the statistical analysis here is a little off-base.

In spite of our problems, we will build a relatively simple-minded set of descriptive statistics. We will average two metrics: the peak stake for a session and the duration of the session. Both of these values have some statistical problems. The peak stake, for instance, is already a summary number. We have to be cautious in our use of summarized numbers, since we have lost any sense of the frequency with which the peaks occured. For example, a player may last 250 cycles of play, with a peak stake of 130. We don't know if that peak occurred once or 100 times out of that 250. Additionally, the length of the session has an upper bound on the number of cycles. This forces the distribution of values to be skewed away from the predictable distribution.

We will design a `Statistics` class with responsibility to retain and summarize a list of numbers and produce the average (also known as the mean) and standard deviation. The `Simulator` can then use this this `Statistics` class to get an average of the maximum stakes from the list of session-level measures. The `Simulator` can also apply this `Statistics` class to the list of session durations to see an average length of game play before going broke.

We can encapsulate this statistical processing in two ways: we could extend an existing class or we could delegate the statistical functions to a separate class. If we extend the library `java.util.List`, we can add the needed statistical summary features; given this new class, we can replace the original `List` of sample values with a `StatisticalList` that both saves the values and computes descriptive statistics. In addition to delegation, we have two choices for implementation of this extended version of `List`, giving us three alternative designs.

1. Extend `LinkedList`. In this case, we are simply adding two new methods to the existing `LinkedList` implementation. However, our new methods would not apply to `ArrayList` or `Vector`.

2. Extend `AbstractList`. However, in doing this we would need to provide the implementation details of the list structure itself. In effect, we would reimplement `LinkedList` or `ArrayList`.

3. Create a separate class that computes statistics on a `List` given as an argument to the methods of the statistical class. In this case, our statistical methods will work with any subclass that implements the interface `List`. This can be applied to any of `LinkedList`, `ArrayList` or `Vector`.

Alternative three -- a separate statistical class -- has the most reuse potential. We'll create a simple class with two methods: `mean` and `stdev` to compute the mean and standard deviation of a `List` of `Integer` objects. This can be used in a variety of contexts, and allows us the freedom to switch `List` implementation classes without any other changes.

The detailed algorithms for mean and standard deviation are provided in Statistical Algorithms.

Since our processes are relative simple, stateless algorithms, we don't need any instance variables. Consequently, we'll never need to create an instance of this class. As with `Java.lang.Math`, all of these methods can be declared as static, making them features of the class itself.

## Some Foundations

For those programmers new to statistics, this section covers the Sigma operator, Σ.

**Equation 15.1. Basic Summation**

$$\sum_{i=0}^{n} f(i)$$

The Σ operator has three parts to it. Below it is a bound variable, *i* and the starting value for the range, written as *i*=0. Above it is the ending value for the range, usually something like *n*. To the right is some function to execute for each value of the bound variable. In this case, a generic function, *f*(*i*). This is read as "sum *f*(*i*) for *i* in the range 0 to *n*".

One common definition of Σ uses a closed range, including the end values of 0 and *n*. However, since this is not a helpful definition for software, we will define Σ to use a half-open interval. It has exactly *n* elements, including 0 and *n*-1; mathematically, $0 \leq i < n$.

Consequently, we prefer the following notation, but it is not often used. Since statistical and mathematical texts often used 1-based indexing, some care is required when translating formulae to programming languages that use 0-based indexing.

**Equation 15.2. Summation with Half-Open Interval**

$$\sum_{0 \leq i < n} f(i)$$

Our two statistical algorithms have a form more like the following function. In this we are applying some function, *f*(), to each value, $x_i$ of an array. When computing the mean, there is no function. When computing standard deviation, the function involves subtracting and multiplying.

**Equation 15.3. Summing Elements of an Array, *x***

$$\sum_{0 \leq i < n} f(x_i)$$

We can transform this definition directly into a for loop that sets the bound variable to all of the values in the range, and does some processing on each value of the List of Integers. This is the Java implementation of Sigma. This computes two values, the sum, `sum` and the number of elements, `n`.

**Example 15.1. Java Sigma Iteration**

```
int sum= 0;
for( int i= 0; i != theList.size(); ++i ) { ❶
    int xi= ((Integer)theList.get(i)).intValue(); ❷
    // int fxi = processing of xi ❸
    sum += fxi;
}
int n= theList.size();
```

❶ Get the size of `theList`. Execute the body of the loop for all values of `i` in the range 0 to the number of elements-1.

❷ Fetch item `i` from `theList`. This is an `Object`, which we cast to be an `Integer`. We then get the int value of this item and assign it to `xi`.

❸ For simple mean calculation, this statement does nothing. For standard deviation, however, this statement computes the measure of deviation from the average.

This is the Python implemention of Sigma. This computes two values, the sum, `sum` and the number of elements, `n`.

**Example 15.2. Python Sigma Iteration**

```
sum= 0
for i in range(len(theList)): ❶
    xi= theList[i] ❷
    # fxi = processing of xi ❸
    sum += fxi
n= len(theList)
```

❶ Get the length of `theList`. Execute the body of the loop for all values of `i` in the range 0 to the number of elements-1.

❷ Fetch item `i` from `theList` and assign it to `xi`.

❸ For simple mean calculation, this statement does nothing. For standard deviation, however, this statement computes the measure of deviation from the average.

More advanced Python programmers may be aware that there are several ways to shorten this loop down to a single expression using the `sum` function as well as list displays.

In the usual mathematical notation, an integer index, *i* is used. In Java or Python it isn't necessary to use the formal integer index. Instead, an iterator can be used to visit each element of the list, without actually using an explicit numeric counter. In Java, the use of an iterator is shown below.

**Example 15.3. Java Sample Values by Iterator**

```
int sum= 0;
for( Iterator i= theList.iterator(); i.hasNext();  ) { ❶
    int xi= ((Integer)i.next()).intValue(); ❷
    // int fxi = processing of xi ❸
    sum += fxi;
}
int n= theList.size();
```

❶ Get an `Interator` over all items of `theList`. Execute the body of the loop for all items in the iterator.

❷ Fetch the next item from the `Interator`, `i`. This is an `Object`, which we cast to be an `Integer`. We then get the int value of this item and assign it to `xi`.

❸ For simple mean calculation, this statement does nothing. For standard deviation, however, this statement computes the measure of deviation from the average.

In Python, the iterator is implied, and the processing simplifies to the following.

**Example 15.4. Python Sample Values by Iterator**

```
for xi in theList: ❶
    # fxi = processing of xi ❷
    sum += fxi
n= len(theList)
```

❶ Execute the loop assigning each item of of `theList` to `xi`.

❷ For simple mean calculation, this statement does nothing. For standard deviation, however, this statement computes the measure of deviation from the average.

These iterator-based formulations can be slightly faster when using a `LinkedList` because this class is optimized for exactly this kind of sequential access.

## Statistical Algorithms

Computing the mean of a list of values is relatively simple. The mean is the sum of the values divided by the number of values in the list. Since the statistical formula is so closely related to the actual loop, we'll provide the formula, followed by an overview of the code.

**Equation 15.4. Mean**

$$\mu_x = \frac{\sum\limits_{0 \le i < n} x_i}{n}$$

The definition of the Σ mathematical operator leads us to the following method for computing the mean:

**Procedure 15.1. Computing Mean**

1. intialize sum, *s*, to zero
2. for each value, *i*, in the range 0 to the number of values in the list, *n*:
    a. add element $x_i$ to *s*
3. return *s* divided by the number of elements, *n*

The standard deviation can be done a few ways, but we'll use the formula shown below. This computes a deviation measurement as the square of the difference between each sample and the mean. The sum of these measurements is then divided by the number of values times the number of degrees of freedom to get a standardized deviation measurement. Again, the formula summarizes the loop, so we'll show the formula followed by an overview of the code.

**Equation 15.5. Standard Deviation**

$$\sigma_x = \sqrt{\frac{\sum_{0 \le i < n} (x_i - \mu_x)^2}{n - 1}}$$

The definition of the Σ mathematical operator leads us to the following method for computing the standard deviation:

**Procedure 15.2. Computing Standard Deviation**

1. compute the mean, *m*
2. intialize sum, *s*, to zero
3. for each value, $x_i$ in the list:
    a. compute the difference from the mean, *d* as $x_i$ - *m*
    b. add $d^2$ to *s*. This is typically done as *d*d* in Java, since there is no “squared” operator. In Python, this can be *d***2.
4. compute the variance, *v*, as *s* divided by (*n* - 1). This *n* - 1 value reflects the statistical notion of “degrees of freedom”, which is beyond the scope of this book.
5. return the square root of the variance, *v*.

### Tip

For programmers new to Java, the `java.lang.Math` contains the `Math.sqrt`, which computes square roots.

For programmers new to Python, the `math` module contains the `math.sqrt`, which computes square roots.

Programmers who have the Python `numeric` module installed will find that this module provides some alternatives to the designs shown in this section. Since this module is optional, we won't cover it any any depth here. However, it can simplify the methods for computing mean and standard deviation.

## Design

`IntegerStatistics` computes several simple descriptive statistics of `Integer` values in a `List`.

### Constructors

- `IntegerStatistics();`

### Methods

- `static double mean(List aList);`

  Computes the mean of the `List` of `Integer` values.

- `static double stdev(List aList);`

  Computes the standard deviation of the `List` of `Integer` values.

## Deliverables

There are three deliverables for this exercise. These classes will include the complete Javadoc comments or Python dostring.

- The `IntegerStatistics` class.
- A unit test of the `IntegerStatistics` class that some simple `LinkedList`, `ArrayList`, and `Vector` test data. The results can be checked with a spreadsheet.
- An update to the overall `Simulator` that gets uses an `IntegerStatistics` object to compute the mean and standard deviation of the peak stake. It also computest the mean and standard deviation of the length of each session of play.

Here is some standard deviation unit test data, some intermediate results and the correct answers given to 6 significant digits. Your answers should be the same to the precision shown.

| Sample Value |
|---|
| 9 |
| 8 |
| 5 |
| 9 |
| 9 |
| 4 |
| 5 |
| 8 |
| 10 |
| 7 |
| 8 |
| 8 |

| | |
|---|---|
| sum | 90 |
| mean | 7.5 |

| | |
|---|---|
| sum *d***d* | 608.668 |
| stdev | 1.88293 |

# Chapter 16. Player Random

**Table of Contents**

This section will introduce a simple subclass of `Player` who bets at random.

## Overview

One possible betting strategy is to bet completely randomly. This serves as an interesting benchmark for other betting strategies.

We'll write a subclass of `Player` which steps through all of the bets available on the `Wheel`, selecting one or more of the available outcomes at random. This `Player`, like others, will have a fixed initial stake and a limited amount of time to play.

The `Wheel` class can provide an `Iterator` over the collection of `Bin` instances. We could revise `Wheel` to provide a `binIterator` method that we can use to return all of the `Bins`. From each `Bin`, we will need an iterator we can use to return all of the `Outcomes`.

To collect a list of all possible `Outcomes`, we would use the following algorithm:

**Procedure 16.1. Locating all Outcomes**

1. **Empty List of Outcomes.** Create an empty list of all `Outcomes`, `allOC`.

2. **Get Bin Iterator.** Get the Iterator from the `Wheel` that lists all `Bins`.
   a. **For Each Bin**
      i. **Get Outcome Iterator.** Get the Iterator that lists all `Outcomes`.
      ii. **For Each Outcome**
         A. **Save Outcome.** Save a reference to each `Outcome` in the list of all known outcomes, `allOC`.

To place a random bet, we would use the following algorithm:

**Procedure 16.2. Placing a Random Bet**

1. Get the size of the pool of all possible `Outcomes`, *s*.
2. Get a random number, *u*, from zero to the total size-1. That is, 0 <= *u* <= *s*-1.
3. Return element *u* from the pool of `Outcomes`.

## Design

`PlayerRandom` is a `Player` who places bets in Roulette. This player makes random bets around the layout.

### Fields

- Java: `java.util.Random rng ;`

  Python: `rng`

  Generates the next random number.

### Constructors

-
  ```
  PlayerRandom(Table aTable,
               Random aGenerator);
  ```

  This uses the `super` construct to invoke the superclass constructor using the `Table`. Then it saves the random number generator. This could be an instance of either `Random` or `NonRandom`.

  For those new to Java, see Java Subclass Constructors. For those new to Python, see Python Subclass Constructors.

### Methods

- `void placeBets();`

  Updates the `Table` with a randomly placed bet.

## Deliverables

There are five deliverables from this exercise. The new classes need Javadoc comments or Python docstrings.

- Updates to the `Bin` to return an iterator over available `Outcomes`

- Updates to the `Wheel` to return an iterator over available `Bins`
- The `PlayerRandom` class.
- A unit test of the `PlayerRandom` class. This should use the NonRandom number generator to iterate through all possible `Outcomes`.
- An update to the overall `Simulator` that uses the `PlayerRandom`.

# Chapter 17. Player 1-3-2-6

**Table of Contents**

This section will describe a player who has a complex internal state. We will also digress on the way the states can be modeled using a group of polymorphic classes. This section also has an advanced exercise that shows some alternative implementations for the state objects, using the Singleton design pattern.

## Overview

On the Internet, we found descriptions of a betting system called the “1-3-2-6” system. This system looks to recoup losses by waiting for four wins in a row. The sequence of numbers (1, 3, 2 and 6) are the multipliers to use when placing bets after winning. At each loss, the sequence resets to the multiplier of 1. At each win, the multiplier is advanced. After one win, the bet is now 3x. After a second win, the bet is reduced to 2x, and the winnings of 4x are “taken down” or removed from play. In the event of a third win, the bet is advanced to 6x. Should there be a fourth win, the player has doubled their money, and the sequence resets.

This betting system makes our player more stateful than in previous betting systems. When designing `SevenReds`, we noted that this player was stateful, but deferred any more serious design consideration until now.

In this case, the description of the betting system seems to identify four states: no wins, one win, two wins, and three wins. In each of these states, we have specific bets to place, and state transition rules that tell us what to do next. The following table summarizes the states, the bets and the transition rules.

Table 17.1. 1-3-2-6 Betting States

| | | **Next State** | |
|---|---|---|---|
| **State** | **Bet** | **On Win** | **On Loss** |
| No Wins | 1 | One Win | No Wins |
| One Win | 3 | Two Wins | No Wins |
| Two Wins | 2 | Three Wins | No Wins |
| Three Wins | 6 | No Wins | No Wins |

When we are in a given state, the table gives us the amount to bet in the *Bet* column. If this bet wins, we transition to the state named in the *Win* column, otherwise, we transition to the state named in the *Lost* column. We always start in the No Wins state.

We can exploit the **State** design pattern to design this more sophisticated player. This pattern suggests that we design a hierarchy of classes to represent these four states. Each state will have a slightly different bet amount, and a different next state when a bet wins. Each individual state class will be relatively simple, but we will have isolated the processing unique to each state into separate classes.

One of the consequences of the **State** design pattern is that it obligates us to define the interface between the `Player` and the object that holds the `Player`'s current state. It seems best to have the state object follow our table and provide three methods: `currentBet`, `nextWon`, and `nextLost`. The `Player` can use these methods of the state object to place bets and pick a new state.

The state's `currentBet` method will construct a `Bet` from an `Outcome` that the `Player` keeps, and the multiplier that is unique to the state. As the state changes, the multiplier moves between 1, 3, 2 and 6.

The state's `nextWon` method constructs a new state object based on the state transition table when the last bet was a winner.

The state's `nextLost` method constructs a new state based on the state transition table when the last bet was a loser. In this case, all of the various states create a new instance of the `NoWins` object, resetting the multiplier to 1 and starting the sequence over again.

**Soapbox On Polymorphism**

One very important note is that we never have to check the class of any object. This is so important, we will repeat it here.

## Important

We don't use `instanceof`.

We use *polymorphism* and design all subclasses have the same interface.

We find that `instanceof` is sometimes used by beginning Java designers who have failed to properly delegate processing to the subclass. Often, when a responsibility has been left out of the class hierarchy, it is allocated to the client object. The typical situation is often the following:

**Example 17.1. Java `instanceof`**

```
if ( x instanceof AClass ) {
    Processing that should be part of AClass
}
```

In all cases, uses of `instanceof` must be examined critically. This will usually lead three changes. First, you can refactor the functionality into the class being referenced by `instanceof`. Second, you will add default processing to the superclass so that all other classes do not have this feature. Finally, you will simply call the refactored method added to the class hierarchy.

This refactoring leads to a class hierarchy that has the property of being *polymorphic*: all of the subclasses have the same interface: all objects of any class in the hierarchy are interchangable. Each object is, therefore, responsible for correct behavior. More important, a client object does not need to know which subclass the object is a member of: it simply invokes methods which are defined with a uniform interface across all subclasses.

In Python, however, the `type` function is necessary as a stand-in for the compile-time type-checking that Java does. The `type` function should be used exclusively to check arguments to methods for the correct built-in type. Any other use is a symptom of mis-allocated responsibility.

## Questions and Answers

**Q:** Why code the state as objects?

**A:** The reason for encoding the states as objects is to encapsulate the information or behavior associated with that state. In this case, we have both the bet amount and the rules for transition to next state. While simple, these are still unique to each state.

Since this is a book on design, we feel compelled to present the best design. In games like blackjack, the player's state may have much more complex information or behavior. In those games, this design pattern will be very helpful. In this one case only, the design pattern appears to be over-engineered.

We will use this same design pattern to model the state changes in the Craps game itself. In the case of the Craps game, there is additional information as well as behavior changes. When the state changes, bets are won or lost, bets are working or not, and outcomes are allowed or prohibited.

**Q:** Isn't it simpler to code the state as a number? We can just increment when we win, and reset to zero when we lose.

**A:** The answer to all “isn't it simpler” questions is “yes, but...”. In this case, the full answer is “yes, but what happens when you add a state or the states become more complex?”

This question arises frequently in OO programming. Variations on this question include “Why is this an entire object?” and “Isn't an object over-engineering this primitive type?” See Why is `Outcome` a separate class? Each object that is an instance of `Outcome` only has two attributes; why not use an array of Strings for the names, and a parallel array of integers for the odds? FAQ entry on the `Outcome` class for additional background on this.

Our goal in OO design is to isolate responsibility. First, and most important, we can unambiguously isolate the responsibilities for each individual state. Second, we find that it is very common that only one state changes, or new states get added. Given these two conditions, the best object model is separate state objects.

**Q:** Doesn't this create a vast number of state objects?

**A:** Yes.

There are two usual follow-up questions: “Aren't all those objects a lot of memory overhead?” or “...a lot of processing overhead?”

Since Java and Python remove unused objects, the old state definitions are cleaned up by the garbage collection thread. A few tests will demonstrate that the Java memory management is efficient and reliable.

Object creation is an overhead that we can control. One common approach is to use the **Singleton** design pattern. In this case, this should be appropriate because we only want a single instance of each of these state classes.

Note that using the **Singleton** design pattern doesn't change any interfaces except the initialization of the `Player1326` object with the starting state.

**Q:** Is Polymorphism necessary?

**A:** In some design patterns, like **State** and **Command**, it is essential that all subclasses have the same interface and be uniform, indistinguishable, almost anonymous instances. Because of this polymorphic property, the objects can be invoked in a completely uniform way.

In our exercise, we will design a number of different states for the player. Each state has the same interface. The actual values for the instance variables and the actual operation implemented by a subclass method will be unique. Since the interfaces are uniform, however, we can trust all state objects to behave properly.

There are numerous designs where polymorphism doesn't matter at all. In many cases, the anonymous uniformity of subclasses isn't relevant. When we move on to example other casino games, we will see many examples of non-polymorphic class hierarchies. This will be due to the profound differences between the various games and their level of interaction with the players.

## Design

There are a number of design elements: the superclass for the states, plus the individual state classes, and the actual subclass of `Player` that uses these states.

This version of the design will use a simpler design that constructs individual state objects on every state change. Once this is working, it can be replaced with a proper **Singleton** design to see how much that improves performance.

## Player1326 State

`Player1326State` is the superclass for all of the states in the 1-3-2-6 betting system.

### Fields

- `Player1326 player ;`

  The player who is currently in this state. This player will be used to provide the `Outcome` on which we will bet.

### Constructors

- `Player1326State(Player1326 player);`

  The constructor for this class saves the `Player1326` which will be used to provide the `Outcome` on which we will bet.

### Methods

- `abstract Bet currentBet();`

  Constructs a new `Bet` from the player's `outcome` information. Each subclass has a different multiplier used when creating this bet.

  In Java, this method can be declared as abstract. Each subclass will provide a unique implementation for this method.

  In Python, this method should raise the `NotImplementedException`. This is a big debugging aid, it helps us locate subclasses which did not provide a method body. This raise statement is the functional equivalent of the Java abstract declaration.

- `abstract Player1326State nextWon();`

  Constructs the new `Player1326State` instance to be used when the bet was a winner.

  In Java, this method can be declared as abstract. Each subclass will provide a unique implementation for this method.

  In Python, this method should raise the `NotImplementedException`.

- `Player1326State nextLost();`

  Constructs the new `Player1326State` instance to be used when the bet was a loser. This method is the same for each subclass: it creates a new instance of `Player1326NoWins`. It is not abstract, but actually defined in the superclass to assure that it is available for each subclass.

### First Soapboax on Refactoring

This class can be simplified slightly to have the bet multiplier coded as an instance variable, `betAmount`. If we do this, the constructor can set it to a value of 1, 3, 2 or 6. Currently, each subclass has a unique `currentBet` method. If we use the `betAmount` value, the `currentBet` method can be refactored into the superclass. This would simplify each sub-state to be only a constructor that sets the `betAmount` multiplier.

Similarly, we could have the next state after winning defined as an instance variable, `nextStateWin`. We can initialized this during construction. Then the `nextWon` method could also be refactored into the superclass, and would return the value of the `nextStateWin` instance variable.

While having all of the state's methods in the superclass is a slight simplification, it is also atypical. We leave this change as a project for a more advanced student.

## Player1326 No Wins

`Player1326NoWins` defines the bet and state transition rules in the 1-3-2-6 betting system. When there are no wins, the base bet value of 1 is used.

### Methods

- `Bet currentBet();`

  Constructs a new `Bet` from the player's `outcome` information. The bet multiplier is 1.

- `Player1326State nextWon();`

  Constructs the new `Player1326OneWin` instance to be used when the bet was a winner.

## Player1326 One Win

`Player1326NoWins` defines the bet and state transition rules in the 1-3-2-6 betting system. When there is one wins, the base bet value of 3 is used.

### Methods

- `Bet currentBet();`

Constructs a new `Bet` from the player's `outcome` information. The bet multiplier is 3.

- `Player1326State nextWon();`

  Constructs the new `Player1326TwoWins` instance to be used when the bet was a winner.

## Player1326 Two Wins

`Player1326NoWins` defines the bet and state transition rules in the 1-3-2-6 betting system. When there are two wins, the base bet value of 2 is used.

### Methods

- `Bet currentBet();`

  Constructs a new `Bet` from the player's `outcome` information. The bet multiplier is 2.

- `Player1326State nextWon();`

  Constructs the new `Player1326ThreeWins` instance to be used when the bet was a winner.

## Player1326 No Wins

`Player1326NoWins` defines the bet and state transition rules in the 1-3-2-6 betting system. When there are three wins, the base bet value of 6 is used.

### Methods

- `Bet currentBet();`

  Constructs a new `Bet` from the player's `outcome` information. The bet multiplier is 6.

- `Player1326State nextWon();`

  Constructs the new `Player1326NoWins` instance to be used when the bet was a winner.

## Player1326

`Player1326` follows the 1-3-2-6 betting system. The player has a preferred `Outcome`, an even money bet like red, black, even, odd, high or low. The player also has a current betting state that determines the current bet to place, and what next state applies when the bet has won or lost.

### Fields

- `Outcome outcome ;`

This is the player's preferred outcome.

- `Player1326State myState ;`

  This is the current state of the 1-3-2-6 betting system. It will be an instance of one of the four states: No Wins, One Win, Two Wins or Three Wins.

### Constructors

- `Player1326();`

  Initializes the state and the outcome. The `myState` is set to the initial state of an instance o0f `Player1326NoWins`. The `outcome` is set to some even money proposition, for example `"Black"`.

### Methods

- `void placeBets();`

  Updates the `Table` with a bet created by the current state. This method delegates the bet creation to `myState` `currentBet`.

- `void win(Bet bet);`

  Uses the superclass method to update the stake with an amount won. Uses the current state to determine what the next state will be by calling `myState`'s `nextWon` method and saving the new state in `myState`

- `void lose(Bet bet);`

  Uses the current state to determine what the next state will be. This method delegates the next state decision to `myState`'s `nextLost`, method saving the result in `myState`.

## Deliverables

There are eight deliverables for this exercise. Additionally, there is an optional, more advanced design exercise in a separate seciotn.

- The five classes that make up the `Player1326State` class hierarchy.
- The `Player1326` class.
- A unit test of the `Player1326` class. This test should synthesize a fixed list of `Outcomes`, `Bins`, and calls a `Player1326` instance with various sequences of reds and blacks. There are 16 different sequences of four winning and losing bets. These range from four losses in a row to four wins in a row.
- An update to the overall `Simulator` that uses the `Player1326`.

## Advanced Exercise

The object creation for each state change can make this particular player rather slow. Using the **Singleton** design pattern can make this application run faster. The difference in performance is small for this application, but can be huge for other applications. We note that the **Singleton** design pattern assures that only a single instance of a given class exists, guaranteeing a single centralized object which can have a number of consequences. First, it can prevent problems from duplicate use of precious resources. Second, it can improve performance and reduce memory consumption.

The general idea behind the **Singleton** design pattern is to assure that only a single instance of a given class ever exists. This is done by avoiding the use of an explicit constructor. Instead, a static method is provided by the class that will return the one-and-only instance of the object. Because of the technical differences in Java and Python, we'll cover each implementation in some detail.

The deliverables for this exercise are revisions to the `Player1326State` class hierarchy to implement the **Singleton** design pattern. This will not change any of the existing unit tests, demonstrations or application programs.

### Singleton Design in Java

To implement the **Singleton** design pattern for the entire state class hierarchy, we must add a static variable, `theInstance`, initially `null`, to each individual subclass of `Player1326State`. Additionally, we have to add a `getInstance` method to each subclass. Finally, we can make the constructor `protected` in the superclass to prevent any other class from using it via the `new` operator.

Note that we can't inherit a single superclass definition of `theInstance` variable or `getInstance` method. Being static, these would be shared by all objects of all four subclasses. We would only have a single `Player1326State` object, and it would be the initially constructed object. Consequently, we need to have a distinct instance variable and method in each subclass, so that an instance of each distinct subclass gets created.

This *aspect* of this class hierarchy has to be included by a tedious cut-and-paste process. It might be nice to specify that this piece of programming is copied out of a template into each class, assuring consistent implementation of the **Singleton** design pattern. There are a few automated approaches to this, including tools for *aspect-oriented programming* and *literate programming*. Both of these are areas for further investigation, well outside the scope of this book.

The `Player1326` constructor would be changed to use the `getInstance` method of `Player1326NoWins` to create the initial state. We have to remove the creation a new instance via `new Player1326NoWins()` and replace this with `Player1326NoWins.getInstance()`.

Each state's `nextWon` and `nextLost` methods would have to use the `getInstance` method to get the next state instance. By removing all of the individual `new` operations, we assure that objects are only made available through `getInstance`, controlling the number of instances actually created.

#### Java Singleton Design

A class the implements the **Singleton** design pattern has the following elements.

```
 Player1326 {
  static Player1326State theInstance = null;
  static Player1326State getInstance();
}
```

The getInstance method checks `theInstance`, if it is `null`, it creates a new instance, setting `theInstance`. This method returns `theInstance`, a reference to the one-and-only instance of this class.

We note that the compile-time binding in Java forces us to repeat these two static elements in each class. There is some administrative overhead in assuring that this aspect of the **Singleton** pattern is repeated in each subclass. In Python, however, the late binding makes this slightly simpler.

## Singleton Design in Python

This class can be sped up by using the **Singleton** design pattern for the entire state class hierarchy. In Python, we have two choices for dealing with the various singleton instances. The most common solution is to create module-level variables at import time; Python assures that each module is only important once. A second solution is to implement a Java-like singleton design in the classes.

Because of the deferred binding in Python, we can easily have each class contain references module-level variables that won't be created until *after* the class is defined. The variables don't exist when the class is defined, but they will exist when the object methods are actually executed. Each class can then expect a module-level variable with a name like `theNoWinsState`. These four variables are created by the module after the definitions of the classes.

### Module Implementation of the Singleton Pattern in Python

The module-level instance variable implementation would look like the following.

**Example 17.2. Python `player` Module**

```
class Player1326State:
    def __init__( self ):
        pass
    other superclass definitions

class Player1326NoWins( Player1326State ):
    def __init__( self ):
        pass
    def nextStateWon( self ):
        return player.theOneWinState ❶
    the rest of the no wins class definition

Player1326OneWins( Player1326State ):
    the rest of the one win class definition

theNoWinsState= Player1326NoWins()
theOneWinState= Player1326OneWin() ❷
```

1. A reference to a module-level variable, `player.theOneWinState`, that will be created later on during the module import. The module name qualification is required to indicate the context in which the variable was created.
2. This creates a module-level variable, `theOneWinState`, used by the class declarations.

The Java-style declaration means that we have a `theInstance` variable which contains the one-and-only instance for this class. Note that we have two choices for handling the object creation. We can override the `__new__` method, or we can provide a `getInstance` method. We'll focus on the `getInstance` method because it's most like Java.

For programmers new to Python, there are two small syntax changes that make a variable or method part of the class and not part of each individual instance. First, instance variables must be created by `__init__` and qualified with the instance name (usually `self`). If, instead, we simply place a variable in the class definition, this variable belongs to the class, and therefore it belongs to every instance of the class. Second, if we call a method using an object name, the method is called with that given instance as the value for `self`. If, instead, we call a method using the class name, the method is called for the class as a whole.

## Python Singleton Class

The Java-like singleton has an implementation would look like the following.

**Example 17.3. Python Singleton With Class Variables**

```
class Player1326State:
    def __init__( self ):
        the rest of the superclass definition

class Player1326NoWins( Player1326State ):
    theInstance= None ❶
    def __init__( self ):
        the rest of the class definition
    def getInstance( self ): ❷
        if not self.theInstance:
            self.theInstance= Player1326NoWins()
        return self.theInstance
    def nextStateWon( self ):
        return Player1326OneWins.getInstance() ❸
        the rest of the no wins class definition

Player1326OneWins( Player1326State ):
    theInstance= None
    the rest of the one win class definition
```

1. The `theInstance` variable is part of the class, and therefore common among all instances. We can refer to it either as `self.theInstance` or as `Player1326NoWins.theInstance`. Each subclass must have this declaration.
2. If necessary, create an instance of this class. Return the one-and-only instance of this class. Because of Python's late binding, this does not have to be repeated in each

subclass.

❸ A reference to the `getInstance` in the target class that returns the one-and-only instance of the `Player1326OneWins.` class

The use of module-level singletons is a common idiom in Python applications. It suffers from the limitation of making it difficult to define subclasses properly. This limitation arises because an important feature of the class are the module-level variables, which are created separately from the class. The following scenario should clarify the situations under which module variables are a problem.

Consider the situation where we have the Player1326 packaged in a single module file that includes the Player1326 class and the Player1326State classes. This module is imported into the main application to provide the definition of the player strategy. We have a variation on this strategy, so we need to extend the class definitions with subclasses to implement this variation. We have two choices for packaging this extension.

- We update the module file to add additional classes and module variables. While simple, we may elect to leave this file untouched because of a license agreement.
- Our application imports the original module and derives new subclasses from it. We will also have to create global variables in our application to define singleton instances of our new states. Assuring that the state classes have singleton instances is the kind of complexity that makes maintenance and enhancement expensive.
- We create a module file that imports the original module file, and adds our extensions to it. We have to be careful with our import so that this two-part import is transparent to client modules and classes. Our derived module file must have the necessary module variables defining singleton instances of our new states.

We feel that the point of OO software is to promote reuse, extension and flexibility. We find that module-level variables are a potentially obscure complexity. The alternative is to make each **Singleton** class self-contained.

# Chapter 18. Player Cancellation

**Table of Contents**

This section will describe a player who has a complex internal state that can be modeled using existing library classes.

## Overview

One method for tracking the lost bets is called the “cancellation” system or the “Labouchere” system. The player starts with a betting budget allocated as a series of numbers. The usual example is 1, 2, 3, 4, 5, 6. Each bet is sum of the first and last numbers in the last. In our example, the end values of 1+6 leads the player to bet 7. When the player wins, they cancel the two numbers used to make the bet. In the event that all the numbers are cancelled, the player resets the sequence of numbers and starts again. For each loss, however, the player adds the amount of the bet to the end of the sequence; this is a loss to be recouped. This adds the loss to the amount bet to assure that the next winning bet both recoups the most recent loss and provides a gain. Multiple winning bets will recoup multiple losses, supplemented with small gains.

Here's an example of the cancellation system using 1, 2, 3, 4, 5, 6.

1. Bet 1+6. A win. Cancel 1 and 6 leaving 2, 3, 4, 5.
2. Bet 2+5. A loss. Add 7 leaving 2, 3, 4, 5, 7.
3. Bet 2+7. A loss. Add 9 leaving 2, 3, 4, 5, 7, 9.
4. Bet 2+9. A win. Cancel 2 and 9 leaving 3, 4, 5, 7.
5. Next bet will be 3+7.

**State.** The player's state is a list of individual bet amounts. This list grows and shrinks; when it is empty, the player leaves the table. We can keep a `List` of individual bet amounts. The total bet will be the first and last elements of this list. Wins will remove elements from the collection; losses will add elements to the collection. Since we will be accessing elements in an arbitrary order, we will want to use an `ArrayList`. We can define the player's state with a simple list of values.

## Design

`PlayerCancellation` uses the cancellation betting system. This player allocates their available budget into a sequence of bets that have an accelerating potential gain as well as recouping any losses.

### Fields

- `List sequence = new List();`

  This `List` keeps the bet amounts; wins are removed from this list and losses are appended to this list. THe current bet is the first value plus the last value.

- `Outcome outcome ;`

  This is the player's preferred outcome.

### Constructors

- `PlayerCancellation();`

  This uses the `resetSequence` method to initalize the sequence of numbers used to establish the bet amount. This also picks a suitable even money `Outcome`, for example, black.

### Methods

- `resetSequence();`

  Puts the initial sequence of six `Integer` instances into the `sequence` variable. These `Integers` are built from the values 1 through 6.

- `void placeBets();`

  Creates a bet from the sum of the first and last values of `sequence`. The first value is at index 0. The last value's position depends on the size of the `List`.

- `void win(Bet bet);`

  Uses the superclass method to update the stake with an amount won. It then removes the fist and last element from `sequence`.

- `void lose(Bet bet);`

  Uses the superclass method to update the stake with an amount lost. It then appends the sum of the first and list elements of `sequence` to the end of `sequence` as a new `Integer` value.

## Deliverables

There are three deliverables for this exercise.

- The `PlayerCancellation` class.
- A unit test of the `PlayerCancellation` class. This test should synthesize a fixed list of `Outcomes`, `Bins`, and calls a `PlayerCancellation` instance with various sequences of reds and blacks. There are 16 different sequences of four winning and losing bets. These range from four losses in a row to four wins in a row. This should be sufficient to exercise the class and see the changes in the bet amount.
- An update to the overall `Simulator` that uses the `PlayerCancellation`.

# Chapter 19. Player Fibonacci

### Table of Contents

This section will describe a player who has an internal state that can be modeled using methods and simple values instead of state objects.

## Overview

A player could use the *Fibonacci Sequence* to structure a series of bets in a kind of cancellation system. The Fibonacci Sequence is 1, 1, 2, 3, 5, 8, 13, .... At each loss, the sum of the previous two bets is used, which is the next number in the sequence. In the event of a win, the last two numbers in the sequence are removed. This allows us to easily track our accumulated losses with bets that could recoup those losses.

In order to compute the Fibonacci sequence, we need to retain the two previous bets as the player's state. In the event of a win, we can compute the previous number in the sequence as the difference in the two bets. In the event of a loss, we can update the two numbers to show the next step in the sequence. The player's state is just these two numeric values.

## Design

`PlayerFibonacci` uses the Fibonacci betting system. This player allocates their available budget into a sequence of bets that have an accelerating potential gain.

### Fields

- `int recent = 1;`

  This is the most recent bet amount.

- `int previous = 0;`

  This is the bet amount previous to the most recent bet amount.

### Constructors

- `PlayerFibonacci();`

### Methods

- `void win(Bet bet);`

  Uses the superclass method to update the stake with an amount won. This will go “backwards” in the sequence. It updates `recent` and `previous` as follows.

1. `newRecent` = `recent` - `previous`
2. `previous` = `recent` - `newRecent`
3. `recent` = `newRecent`

- `void lose(Bet bet);`

  Uses the superclass method to update the stake with an amount lost. This will go “forwards” in the sequence. It updates `recent` and `previous` as follows.

  1. `newRecent` = `recent` + `previous`
  2. `previous` = `recent`
  3. `recent` = `newRecent`

## Deliverables

There are three deliverables for this exercise.

- The `PlayerFibonacci` class.
- A unit test of the `PlayerFibonacci` class. This test should synthesize a fixed list of `Outcomes`, `Bins`, and calls a `PlayerFibonacci` instance with various sequences of reds and blacks. There are 16 different sequences of four winning and losing bets. These range from four losses in a row to four wins in a row. This should be sufficient to exercise the class and see the changes in the bet amount.
- An update to the overall `Simulator` that uses the `PlayerFibonacci`.

# Chapter 20. Conclusion

The game of Roulette has given us an opportunity to build an application with a considerable number of classes and objects. It is comfortably large, but not complex; we have built tremendous fidelity to a real-world problem. Finally, this program produces moderately interesting simulation results.

We note that a great many of our design decisions were not easy to make without exploring a great deal of the overall application's design. There are two ways to do this exploration: design everything in advance or design just enough but remain tolerant of our own ignorance.

Experienced designers can often design an entire, complex application before building any software. The process of doing this design, however, is internally iterative. Some parts are designed in detail, with tolerance for future changes; then other parts are designed in detail and the two design elements reconciled.

For new designers, we can't give enough emphasis to the importance of creating a trial design, exploring the consequences of that design, and then doing rework of that design. Too often, we have seen trial designs finalized into deliverables with no opportunity for meaningful rework. In Chapter 11, *Review of Testability*, we presented one common kind of rework to support more complete testing. In Chapter 12, *Player Class*, we presented another kind of rework to advance a design from a stub to a complete implementation.

We also feel compelled to point out the distinction between relatively active and passive classes in this design. We had several passive classes, like `Outcome`, `Bet` and `Table`, which had few responsibilities beyond collecting a number of related attributes and providing simple functions. We also had several complex, active classes, like `Game`, `BinBuilder` and all of the variations on `Player`. These classes, typically, had fewer attributes and more complex methods. In the middle of the spectrum is the `Wheel`. We find this distinction to be an enduring feature of OO design: there are *things* and *actors*; the things tend to be passive, acted upon by the actors. The overall system behavior emerges from the collaboration among all of the objects in the system; primarily -- but not exclusively -- the behavior of the active classes.

# Craps

This part describes parts of the more complex game of Craps. Craps is a game with two states and a number of state-change rules. It has a variety of kinds of bets, some of which are quite complex.

The chapters of this part presents the details on the game, an overview of the solution, and a series of eleven exercises to build a complete simulation of the game, with a variety of betting strategies. The exercises in this part are more advanced; unlike Part I, “Roulette”, we will often combine several classes into a single batch of deliverables.

There are several examples of rework in this part, some of them quite extensive. This kind of rework reflects three more advanced scenarios: refactoring to generalize and add features, renaming to rationalize the architecture, and refactoring to extract features. Each of these is the result of learning; they are design issues that can't easily be located or explained in advance.

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# Chapter 21. Craps Details

**Table of Contents**

In the first section we will present elements of the game of Craps. Craps is a stateful game, and we'll describe the state changes in some detail.

We will review some of the bets available on the Craps table in some depth. Craps offers some very obscure bets, and part of this obscurity stems from the opaque names for the various bets. Creating this wide variety of bets is an interesting programming exercise, and the first four exercise chapters will focus on this.

Finally, we will describe some common betting strategies that we will simulate. The betting strategies described in Part I, "Roulette" will be applied to Craps bets, forcing us to examine the Roulette solution for reuse opportunities.

## Craps Game

Craps centers around a pair of *dice* with six sides. The 36 combinations form eleven numbers from 2 to 12; additionally, if the two die are equal, this is called a *hardways*, because the number was made "the hard way". The *table* has a surface marked with spaces on which players can place *bets*. The names of the bets are opaque, and form an obscure jargon. There are several broad classification of bets, including those which follow the sequence of dice throws that make up a complete *game*, *propositions* based on only the next throw of the dice, and hardways bets. These bets will be defined more completely, below.

When the bets are placed, the dice are thrown by one of the players. This number resolves the one-roll bets that are winners or losers; it also determines the state change in the game, which may resolve any game-based winners and losers. The first roll of the dice can be an immediate win or loss for the game, or it can establish the *point* for the following rounds of this game. Subsequent rolls either make the point and win the game, roll a seven and lose the game, or the game continues. When the game is won, the winning player continues to shoot; a losing player passes the dice around the table to the next player.

In addition to the bets marked on the table, there are some additional bets which are not marked on the table. Some of these are called *odds bets*, or *free odds bets*, and pay off at odds that depend on the dice, not on the bet itself. An odds bet must be associated with a bet called a *line bet*, and are said to be "behind" the original bet; they can be called "behind the line odds" bets. The four line bets will be defined more fully, below.

### Note

There are slight variations in the bets available in different casinos. We'll focus on a common subset of bets.

The dice form a frequency distribution with values from 2 to 12. An interesting preliminary exercise is to produce a table of this distribution with a small demonstration program. This frequency distribution is central to understanding the often cryptic rules for Craps. See Creating A Dice Frequency Distribution for a small application to develop this frequency distribution.

## Creating A Dice Frequency Distribution

Since Python is interpreted, you can enter the following directly in the interpreter and get the frequency of each number.

**Example 21.1. Python Frequency Distribution**

```
freq= {}
for d1 in range(6):
    for d2 in range(6):
        n= d1+d2+2
        freq.setdefault(n,0)
        freq[n] += 1
print freq
```

In Java, you will have to write and run a short program to produce the frequency distribution.

**Example 21.2. Java Frequency Distribution**

```
class FreqTable {
    public static void main( String[] args ) {
        int[] freq= new int[13];
        for( int n= 0; n != 13; ++n ) { freq[n]= 0; }
        for( int d1= 0; d1 != 6; d1 += 1 ) {
            for( int d2= 0; d2 != 6; d2 += 1 ) {
                int n= d1+d2+2;
                freq[n] += 1;
            }
        }
        for( int n= 2; n != 13; ++n ) {
            System.out.println( "" + n + ": " + freq[n] );
        }
    }
}
```

The Craps game has two states: *point off* and *point on*. When a player begins a game, the point is off; the initial throw of the dice is called the “come out roll”. The number thrown on the dice determines the next state, and also the bets that win or lose. The rules are summarized in the following table.

Table 21.1. Craps Game States

| State | Roll | Bet Resolution | Next State |
|---|---|---|---|
| | 2, 3, 12 | "Craps": Pass bets lose, Don't Pass bets win. | Point Off |

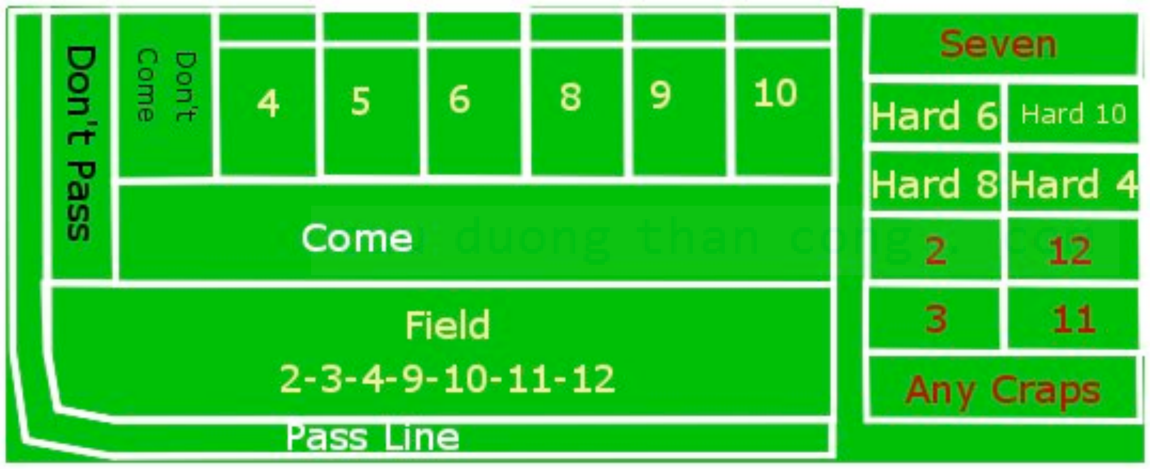
| | | | |
|---|---|---|---|
| Point Off; the Come Out Roll; only Pass and Don't Pass bets allowed. | 7, 11 | "Winner": Pass bets win, Don't Pass bets lose. | Point Off |
| | 4, 5, 6, 8, 9, 10 | | Point On the number rolled, *p*. |
| Point On; any additional bets may be placed. | 2, 3, 12 | Nothing | Point still on |
| | 11 | Nothing | Point still on |
| | 7 | "Loser": all bets lose. The table is cleared. | Point Off |
| | Point, *p* | "Winner": point is made, Pass bets win, Don't Pass bets lose. | Point Off |
| | Non-*p* number | Nothing; Come bets are activated | Point still on |

There is a symmetry to these rules. The most frequent number, 7, is either an immediate winner or an immediate loser. The next most frequent numbers are the six point numbers, 4, 5, 6, 8, 9, 10, which form three sets: 4 and 10 are high odds, 5 and 9 are middle odds, 6 and 8 are low odds. The relatively rare numbers (2, 3, 11 and 12) are handled specially on the first roll only, otherwise they are ignored. Because of the small distinction made between the *craps* numbers (2, 3 and 12), and 11, there is an obscure "C-E" bet to cover both craps and eleven.

## Available Bets

There are three broad classification of bets: those which follow the sequence of dice throws that make up a complete *game*, those based on just the next throw of the dice, called *proposition bets*, and the hardways bets. The game bets are called line bets, can be supplemented with additional odds bets, placed behind the line bet.

The following illustration shows the left half of a typical craps table layout. On the left are the game bets. On the right (in the center of the table) are the single-roll propositions.



Craps Table Layout

When the point is *off*, the player will be making the come out roll, and only certain bets are available. Once the point is *on*, all bets are available.

The bets which are allowed on the come out roll are the *Pass Line* and *Don't Pass Line* bets. These bets follow the action of the player's game. There are several possible outcomes for these two bets.

- Player throws craps (2, 3, or 12). A Pass Line bet loses. A Don't Pass Line bet wins even money on 2 or 3; however, on 12, it returns the bet. This last case is called a “push”; this rule is noted on the table by the “bar 12” legend in the Don't Pass area.
- Player throws 7 or 11. A Pass Line bet wins even money. A Don't Pass Line bet loses.
- Player throws a point number. The point is now *on*. A large white token, marked “on” is placed in one of the six numbered boxes to announce the point. The player can now place an additional odds bet behind the line. Placing a bet behind the Pass Line is called “buying odds on the point”. Placing a bet behind the Don't Pass Line is called “laying odds against the point”. Once the point is on, there are three possible outcomes.
    - The player makes the point before rolling 7. A Pass Line bet wins even money. A Don't Pass Line bet loses. The point determines the odds used to pay the behind the Pass Line odds bet.
    - The player throws 7 before making the point. A Pass Line bet loses. A Don't Pass Line bet pays even money. The point determines the odds used to pay the behind the Don't Pass Line odds bet.
    - The player throws a number other than 7 and the point: the game continues.

Once the point is on, the bets labeled *Come* and *Don't Come* are allowed. These bets effectively form a game parallel to the main game, using a come point instead of the main game point. Instead of dropping the large “on” token in a numbered square on the layout, the house will move the individual Come and Don't Come bets from their starting line into the numbered boxes (4, 5, 6, 8, 9, 10) to show which bets are placed on each point number. There are several possible outcomes for these two bets.

- Player throws craps (2, 3, or 12). A Come Line bet loses. A Don't Come bet wins even money on 2 or 3; it is a push on 12. Established come point bets in the numbered squares remain.
- Player throws 11. A Come Line bet wins even money. A Don't Come bet loses. Established come point bets in the numbered squares remain.
- Player throws a point number (4, 5, 6, 8, 9, or 10). Any come bets in that numbered box are winners -- the come point was made -- and the point determines the odds used to pay the behind the line odds. (Note that if this is the point for the main game, there will be no bets in the box, instead the large “on” token will be sitting there.) New bets are moved from the Come Line and Don't Come Line to the numbered box, indicating that this bet is waiting on that point number to be made. Additional behind the line odds bets can now be placed. If the main game's point was made, the “on” token will be removed (and flipped over to say “off”), and the next roll will be a come out roll for the main game. These bets (with the exception of the free odds behind a Come Line bet) are still working bets.
- The player throws 7 before making the main point. A Come bet loses. A Don't Come bet pays even

money. The bets in the numbered boxes are all losers.

There are four hardways bets. These are bets that 4, 6, 8 or 10 will come up on two equal die (the hard way) before they come up on two unequal die (the easy way) or before a 7 is rolled. Hard 6, for example, is a bet that the pair (3,3) will be rolled before any of the other four combinations (1,5), (2,4), (5,1), (4,2) that total 6, or any of the 6 combinations that total 7. These bets can only be placed when the point is on, but they are neither single-roll propositions, nor are they tied to the game point.

There are additional unmarked bets. One is to make a “place bet” on a number; these bets have a different set of odds than the odds bets behind a line bet. Other unmarked bets are to “buy” a number or “lay” a number, both of which involve paying a commission on the bet. Typically, only the six and eight are bought, and they can only be bought when they are not the point.

There are also a number of one-roll *propositions*, including the individual numbers 2, 3, 7, 11, 12; also *field* (2, 3, 4, 9, 10, 11 or 12), *any craps* (2, 3 or 12), the *horn* (2, 3, 11 or 12), and a *hop bet*. These bets have no minimum, allowing a player to cover a number of them inexpensively.

For programmers new to casino gambling, see Odds and Payouts for more information on odds payments for the various kinds of bets.

## Odds and Payouts

Not all of the Craps outcomes are equal probability. Some of the bets pay fixed odds, defined as part of the bet. Other bets pay odds that depend on the point established.

The basic Pass Line, Don't Pass, Come Line and Don't Come bets are even money bets. A $5 bet wins an additional $5.

The odds of winning a Pass Line bet is 49.3%. The 1:1 payout does not reflect the actual probability of winning.

The points of 4 and 10 have odds of 3 in 36 to win and 6 in 36 to lose. The points of 5 and 9 have odds of 4 in 36 to win and 6 in 36 to lose. The points of 6 and 8 have odds of 5 in 36 to win and 6 in 36 to lose. The odds, therefore are 2:1, 3:2 and 6:5 for these behind-the-line odds bets, respectively.

The combination of a Pass Line bet plus odds behind the line provides the narrowest house edge. For example, a bet on the Pass Line has an expected return of -1.414%. If we place double odds behind the line with an expected return of 0, the net expected return for the combination is -0.471%.

The various proposition bets have odds stated on the table. Note that these rarely reflect the actual odds of winning. For example, a bet on 12 is a 1/36 probability, but only pays 30:1.

There are 1/36 ways to win a hard six or hard eight bet, 10/36 ways to loose and the remaining 25 outcomes are indeterminate. While a hard 6 or hard 8 should pay 10:1, the actual payment is 9:1. Similarly for a hard 4 or hard 10: they should pay 8:1, the actual payment is 7:1.

For programmers new to the game of Craps, see Wrong Betting for more information on the distinction between right betting and wrong betting. This can be ignored by novice programmers. None of our simulated players are wrong bettors, since this involves putting a large amount at risk for a small payout, which violates one of the basic rules of gambling.

### Wrong Betting

Craps has two forms of odds betting: right and wrong. The Pass Line and Come Line, as well as buying odds, are all “right”. The Don't Pass, Don't Come and Laying Odds are all “wrong”. Sometimes wrong betting is also called “the dark side”.

Right betting involves odds that provide a large reward for a small wager. The odds on a Pass Line bet for the number 4 are 2:1, you will win double your bet if the point is made. You put up $10 at risk to make $20.

Wrong betting involves odds that provide a small reward for a large wager. The odds on a Don't Pass Line bet for the number 4 are described as “laid at 2:1” -- in effect it is a 1:2 bet, you will win half of what you bet if the point is missed. You put $20 at risk to make $10.

## Some Betting Strategies

All of the Roulette betting strategies apply to Craps. However, the additional complication of Craps is the ability to have multiple working bets by placing additional bets during the game. The most important of these additional bets are the behind the line odds bets. Since these are paid at proper odds, they are the most desirable bets on the layout. The player, therefore, should place a Line bet, followed by a behind the line odds bet.

The other commonly used additional bets are the Come (or Don't Come) bets. These increase the number of working bets. Since the additional odds bets for these pay proper odds, they are also highly desirable. A player can place a Come bet, followed by a behind the line odds bet on the specific number rolled.

Beyond this, there are the various proposition and hardways bets that can be placed in addition to other bets. While these propositions have odds that are incorrect, some players will count the number of throws in game, and place a “7” bet if the game lasts more than six throws. This is a form of betting against one's self: there is a Pass Line bet that the game will be won, diluted by a 7 bet that the game will be lost. While the common rationale is that the second bet protects against a loss, it also reduces the potential win. We can simulate this kind of betting and examine the potential outcomes.

# Chapter 22. Craps Solution Overview

### Table of Contents

We will present a survey of the classes gleaned from the general problem statement in Problem Statement as well as the problem details in Craps Details. This survey is drawn from a quick overview of the key nouns in these sections.

Given this survey of the candidate classes, we will then do a walkthrough to refine the definitions, and assure ourselves that we have a reasonable architecture. We will make some changes to the preliminary class list, revising and expanding on our survey.

We will also include a number of questions and answers about this preliminary design information. This should help clarify the design presentation and set the stage for the various development exercises in the chapters that follow.

## Preliminary Survey of Classes

We have divided up the responsibilities to provide a starting point for the development effort. The central principle behind the allocation of responsibility is *encapsulation*. In reading the background information and the problem statement, we noticed a number of nouns that seemed to be important parts of the Craps game.

Dice
Bet
Table
Point
Proposition
Number
Odds
Player
House

The following table summarizes some of the classes and responsibilities that we can identify from the problem statement. This is not the complete list of classes we need to build. As we work through the exercises, we'll discover additional classes and rework some of these classes more than once.

We also have a legacy of classes available from the Roulette solution. We would like to build on this infrastructure as much as possible.

**Preliminary Class Structure**

| Class | Responsibilities | Collaborations |
|---|---|---|
| `Outcome` | A name for a particular betting opportunity. Most outcomes have fixed odds, but the behind the line odds bets have odds that depend on a point value. | Collected by `Table` into the available bets for the `Player`; used by `Game` to compute the amount won from the amount that was bet. |
| `Dice` | Selects the winning propositions as well as next state of the game | Used by the overall `Game` to get a next set of winning |

| | | |
|---|---|---|
| `Dice` | Selects the winning propositions as well as next state of the game. | `Outcomes`, as well as change the state of the `Game`. |
| `Table` | A collection of bets placed on `Outcomes` by a `Player`. This isolates the set of possible bets and the management of the amounts currently at risk on each bet. This also serves as the interface between the `Player` and the other elements of the game. | Collects the `Outcomes`; used by `Player` to place a bet amount on a specific `Outcome`; used by `Game` to compute the amount won from the amount that was bet. |
| `Player` | Places bets on `Outcomes`, updates the stake with amounts won and lost. This is the most important responsibility in the application, since we expect to update the algorithms this class uses to place different kinds of bets. Clearly, we need to cleanly encapsulate the `Player`, so that changes to this class have no ripple effect in other classes of the application. | Uses `Table` to place `Bets` on preferred `Outcomes`; used by `Game` to record wins and losses. |
| `Game` | Runs the game: gets bets from `Player`, throws the `Dice`, updates the state of the game, collects losing bets, pays winning bets. This encapsulates the basic sequence of play into a single class. The overall statistical analysis is based on playing a finite number of games and seeing the final value of the `Player`'s stake. | Uses `Dice`, `Table`, `Outcome`, `Player`. |

## A Walkthrough of Craps

A good preliminary task is to review these responsibilities to confirm that a complete cycle of play is possible. This will help provide some design details for each class. It will also provide some insight into classes that may be missing from this overview. A good way to structure this task is to do a CRC walkthrough. For more information on this technique see A Walkthrough of Roulette.

The basic processing outline is the responsibility of the `Game` class. To start, locate the `Game` card.

1. Our preliminary note was that this class “Runs the game.” The responsibilities section has a summary of five steps involved in running the game.
2. The first step is “gets bets from `Player`.” Find the `Player` card.
3. Does a `Player` collaborate with a `Game` to place bets? Note that the game state influences the allowed bets. Does `Game` collaborate with `Player` to provide the state information? If not, add this information to one or both cards.
4. The `Game`'s second step is to throw the `Dice`. Is this collaboration on the `Dice` card?
5. The `Game`'s third step is to update the state of the game. While the state appears to be internal to the `Game`, requiring no collaboration, we note that the `Player` needs to know the state, and therefore should collaborate with `Game`. Be sure this collaboration is documented.
6. The `Game`'s fourth and fifth steps are to pay winning bets and collect losing bets. Does the `Game` collaborate with the `Table` to get the working bets? If not, update the collaborations.

Something we'll need to consider is the complex relationship between the dice, the number rolled on the dice, the game state and the various bets. In Roulette, the wheel picked a random `Bin` which had a simple list of winning bets; all other bets were losers. In Craps, however, we find that we have game bets that are based on changes to the game state, not simply the number on the dice. The random outcome is used to resolve one-roll proposition bets, resolve hardways bets, change the game state, and resolve game bets.

We also note that the house moves Come Line (and Don't Come) bets from the Come Line to the numbered spaces. In effect, the bet is changed from one `Outcome` to another `Outcome`. This means that a `Bet` has a kind of state change, in addition to the `Game`'s state change and any possible `Player` state change.

**Important**

To continue this rant, we find that most interesting IT applications involve stateful objects. Everything that has a state or status, or can be updated, is stateful. Often, designers overlook these state changes, describing them as “simple updates”. However, state changes are almost universally accompanied by rules that determine legal changes, events that precipitate changes, and actions that accompany a state change. Belittling stateful objects causes designers to overlook these additional details. The consequence of ignoring state is software that performs invalid or unexpected state transitions. These kinds of bugs are often insidious, and difficult to debug.

A walkthrough will give you an overview of the interactions among the objects in the working application. You may uncover additional design ideas from this walkthrough. The most important outcome of the walkthrough is a clear sense of the responsibilities and the collaborations required to create the necessary application behavior.

## Questions and Answers

**Q:** Why is `Outcome` a separate class? Each object that is an instance of `Outcome` is merely a number from 2 to 12.

**A:** See the discussion under Why is `Outcome` a separate class? Each object that is an instance of `Outcome` only has two attributes; why not use an array of Strings for the names, and a parallel array of integers for the odds? FAQ for more discussion.

Here we have complex interdependency between the dice, the game states, the bets and outcomes. An outcome has different meanings in different game states: sometimes a 7 is an immediate winner, other times it as an immediate loser. Clearly, we need to isolate these various rules into separate objects to be sure that we have captured them accurately without any confusion, gaps or conflicts.

We can foresee three general kinds of `Outcomes`: the propositions that are resolved by a single throw of the dice, the hardways that are resolved periodically, and the game bets which are resolved when a point is made or missed. Some of the outcomes are only available in certain game states.

The alternative is deeply nested if-statements. Multiple objects introduce some additional details in the form of class declarations, but objects have the advantage of clearly isolating responsibilities, making us more confident that our design will work properly. If-statements only conflate all of the various conditions into a tangle that includes a huge risk of missing an important and rare condition.

**Q:** What is the difference between Dice and Wheel? Don't they both represent simple collections with random selection?

**A:** Perhaps. At the present time, the distinction appears to be in the initialization of the two collections of Bins of the Wheel or Throws of the Dice. We'll revisit the question in some depth in Soapbox on Over-Engineering.

Generally, we are slow to merge classes together without evidence that they are really the same thing. In this case, they appear very similar, so we will note the similarities and differences as we work through the design details. There is a fine line between putting too many things together and splitting too many things apart. Generally, the mistake we see most often is putting too many things together, and resolving the differences through complex if-statements and other hidden processing logic.

# Chapter 23. Outcome Class

**Table of Contents**

This chapter will examine the `Outcome` class, and its suitability for the game of Craps. We'll present some additional code samples to show a way to handle the different kinds of constuctors that this class will need.

## Overview

For Craps, we have to be careful to disentangle the random events produced by the `Dice` and the outcomes on which a `Player` creates a `Bet`. In Roulette, this relationship was simple: a `Bin` was a container of `Outcomes`; a player's `Bet` referenced one of these `Outcomes`. In Craps, however, we have one-roll outcomes, hardways outcomes, plus outcomes that aren't resolved until the end of the game. Keeping this in mind, we'll defer details of dice and game problem until later, and focus on just the bet `Outcomes` first.

There is a rich variety of bet `Outcomes`. We'll itemize them so that we can confirm the responsibilities for this class.

- The Line Bets: these are the Pass Line, Don't Pass Line, Come Line, Don't Come Line. These outcomes have fixed odds of 1:1.

- The four Hardways bets: 4, 6, 8 and 10. These outcomes also have fixed odds which depend on the number.
- The various one-roll propositions. All of these have fixed odds. These are most like the original `Outcome` used for Roulette.
- The six Come-point bets (4, 5, 6, 8, 9 and 10). Each of these has fixed odds. Also, the initial line bet is moved to a point number from the Come Line bet, based on the number shown on the dice. We'll examine these is some detail, below.
- The Odds bets placed behind the Line bets. These have odds based on the point, not the outcome itself. We'll have to look at these more closely, also.
- The six Placed Numbers have odds are based on the number placed. These outcomes have fixed odds. Once the bet is placed, these bets are resolved when the number is rolled or when a game losing seven is rolled.
- The Buy and Lay bets require a commission payment, called a vigorish, when the bet is placed. The outcomes have simple, fixed odds. As with the placed number bets, these bets are resolved when the number is rolled or when a game losing seven is rolled.

Looking more closely at the bets with payout odds that depend on the point rolled, we note that the Come Line (and Don't Come) odds bets are moved to a specific number when that point is established. For example, the player places a Come bet, the dice roll is a 4; the come bet is moved into the box labeled “4”. Any additional odds bet is placed in this box, also.

This leaves us with the Pass Line and Don't Pass Line odds bet, which also depend on the point rolled. In this case, the bets are effectively moved to a specific numbered box. In a casino, a large, white, “on” token in placed in the box. The effect is that same as if the house had moved all the Pass Line bets. The odds bet, while physically behind the Pass Line, is effectively in the box identified by the point. Again, the bet is moved from the 1:1 Pass Line to one of the six numbered boxes; any odds bet that is added will be on a single `Outcome` with fixed odds.

In this case, the existing `Outcome` class still serves many of our needs. Looking forward, we will have to rework `Bet` to provide a method that will change to a different `Outcome`. This will move a line bets to one of the six numbered point boxes.

There are two additional responsibilities that we will need in the `Outcome` class: more complex odds and a house commission. In Roulette, all odds were stated as *n*:1, and our `winAmount` depended on that. In craps, many of the odds have non-unit denominators. Example odds include 6:5, 3:2, 7:6, 9:5. In a casino, the bets are multiples of \$5, \$6 or \$10 to accomodate the fractions.

**Complex Odds.** In our simulation, we are faced with two choices for managing these more complex odds: exact fractions or approximate floating-point values. Since exact rational fractions are not part of the Java class library, we'll use simple `double` values instead of `int` values for the player's stake and the amount won or lost.

An interesting additional feature is to use rational numbers for the stakes and amounts. There are a number of rational number classes available on the Internet, any of which would be suitable for this problem. We will leave it to the interested student to replace the double values with `Rational` values for the player's stake and the amounts won and lost with each bet.

In Java, we will have to replace many instances of `int` with `double`. This is an unpleasant change, but a consequence of starting out with a built-in primitive type. The only effective escape from this kind of change is to use a class in all cases instead of a primitive type. This would allow us to use different subclasses as our design evolved. If, for example, we use `java.lang.Number`, we can switch to any subclass without a complex or sweeping change. The down-side of using a class in Python is that the built-in expression syntax only applies to primitive types. With primitive types we can write `a + b`. With the “language” classes like `Integer`, we have to write something like `new Integer( a.intValue() + b.intValue() )`. With the “math” classes like `BigInteger`, we can write something like `a.add( b )`.

In Python, we don't have static compile-time type checking. We can easily replace an integer result with a double result with no impact throughout the application.

**Commission Payments.** The second extension we have to consider is for the two bets which have a commission when they are created: buy bets and lay bets. The buy bet involves an extra 5% placed with the bet: the player puts down $21, a $20 bet and a $1 commission. A lay bet, which is a wrong bet, involves a risk of a large amount of money against a small win, and the commission is based on the potential winning. For a 2:3 wrong bet, the commission is 5% of the outcome; the player puts down $31 to win $20 if the point is not made.

In both buy and lay cases, the `Player` sees a price to create a bet of a given amount. Indeed, this generalizes nicely to all other bets. Most bets are simple and the price is the amount of the bet. For buy bets, however, the price is 5% of the amount of the bet; for lay bets, the price is 5% of the possible payout. The open question is the proper allocation of responsibility for this price. Is the price related to the `Outcome` or the `Bet`?

When we look at the buy and lay bets, we see that they are based on existing point number `Outcomes` and share the same odds. However, there are three very different ways create a `Bet` on one of these point number `Outcomes`: a bet on the Pass Line (or Don't Pass Line), a bet on the Come Line (or Don't Come Line), and a buy (or lay) bet on the number. When we bet via the Pass Line or Come Line, the Line bet was moved to the point number, and the odds bet follows the Line bet. For this reason, the price is a feature of creating the `Bet`. Therefore, we'll consider the commission as the price of creating a bet and defer it to the `Bet` class design.

We observe that the slight error in the Line bet odds is the house's edge on the Line bet. When we put an odds bet behind the line, the more correct odds dilutes this edge. When we buy a number, on the other hand, the odds are correct and the house takes the commission directly.

## Design

We'll be extending the definition of `Outcome`. We don't want to disturb the simple case of Roulette when we add the more complex case of Craps. We'll do this with an overloaded constructor.

In order to simplify the design, we'll make use of a single method name that two different sets of parameters. In Java, this is accomplished with overloaded methods. Programmers new to Java should see the sidebar Java Overloaded Methods.

## Java Overloaded Methods

In Java, we can use an *overloaded method* for the two version of `winAmount`. This has the effect of providing default values for missing arguments. Typically, we provide a method with all of the arguments, plus a number of other methods with the same name but a different mix of arguments. Each of the overloaded versions will call the "full" version with appropriate default values.

### Example 23.1. Java Default Method Arguments via Overloading

```
class SomeSubClass extends SomeClass  {
    SomeSubClass( int reqArg, int optArg ) {
        super(); ❶
        initialize using reqArg and optArg ❷
    }
    SomeSubClass( int reqArg ) {
        this( reqArg, 1 ); ❸
    }
}
```

❶ We use the super-class initializer explicitly. The explicit-value initialization uses both parameters.

❷ The actual work of the initialization.

❸ A default-value initializer. A default value of `1` is given to the explicit-value initializer for the optional parameter.

We provide default values by having multiple constructors, one of which has a compplete set of arguments that provide explicit values. Other constructors create appropriate defaults and call this explicit constructor with the default values. We do this to assure that exactly one constructor has responsibility for proper initialization of the instance. Other constructors merely provide default values.

In order to simplify the design, we'll make use of a single method name that has optioanl parameters. Programmers new to Python should see the sidebar Python Overloaded Method.

## Python Overloaded Method

In Python, we use optional parameters to provide default values. We declare the default value as part of the method definition. This works well when we are initializing values to any of the immutable object classes. It doesn't, however, work well for mutable lists and mappings; these must be handled specially. The following example shows a simple required argument, followed by an optional argument.

### Example 23.2. Python Default Method Arguments

```
class SomeClass:
    def __init__( self, reqArg, optArg=1 ):
        initialize using optArg
```

Note that Python mutable types (lists and maps) should not be provided as default values for an initializer. This is because one initialization object is created when the class is defined, and all instances will share this singleton initializer object. To avoid this undesirable sharing of an instance of the default value, we have to do the following.

**Example 23.3. Python Default Mutable Method Arguments**

```
class SomeClass:
    def __init__( self, aList=None ):
        if aList:
            initialize using aList
        else:
            default initialization using a fresh []
```

## Outcome Rework

`Outcome` contains a single outcome on which a bet can be placed. In Roulette, each spin of the wheel has a number of `Outcomes`. For example, the "1" bin has the following winning `Outcomes`: "1", "Red", "Odd", "Low", "Column 1", "Dozen 1-12", "Split 1-2", "Split 1-4", "Street 1-2-3", "Corner 1-2-4-5", "Five Bet", "Line 1-2-3-4-5-6", "00-0-1-2-3", "Dozen 1", "Low" and "Column 1".

### Fields

- `String name ;`

  Holds the name of the `Outcome`. Examples include `"1"`, `"Red"`, `"Pass Line"`.

- `int numerator ;`

  Holds the numerator portion of odds for this `Outcome`. This is the amount returned. For right bets in Craps, this is larger than the denominator. For wrong bets, it is smaller than the denominator.

- `int denominator = 1;`

  Holds the denominator portion of odds for this `Outcome`. For Roulette, this is always 1.

### Constructors

-
  ```
  Outcome(String name,
          int odds);
  ```

  Sets the local name and odds from the parameter name and the numerator for the odds. The denominator will be `1`.

-
  ```
  Outcome(String name,
          int numerator,
  ```

```
        int denominator);
```

Sets the local name and odds from the parameter name and odds. Example 1: 6:5 is a right bet, the player will win 6 for each 5 that is bet. Example 2: 2:3 is a wrong bet, they player will win 2 for each 3 that is bet.

### Methods

- `double winAmount(int amount);`

  Returns the product of this `Outcome`'s odds numerator by the given amount, divided by the odds denominator.

- An easy-to-read String output method is also very handy. This should return a String representation of the name and the odds. A form that looks like `1-2 Split (17:1)` works nicely.

## Deliverables

There are two deliverables for this exercise.

- The revised `Outcome` class that handles more complex odds and returns type `double` from `winAmount`.
- A class which performs a unit test of the `Outcome` class. The unit test should create a couple instances of `Outcome`, and establish that the `winAmount` method works correctly.
- A revision to each subclass of `Player` to correctly implement the revised result from `winAmount`. Currently, there are six subclasses of `Player`: `Passenger57`, `SevenReds`, `PlayerRandom`, `Player1326`, `PlayerCancellation`, and `PlayerFibonacci`.

For the more advanced student, locate or develop a class to work with rational numbers, represented as an integer numerator and denominator. Use this for all stakes, odds and bet payoffs, replacing any `double` variables.

# Chapter 24. Throw Class

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Deliverables

In Craps, a throw of the dice may change the state of the game. This close relationship between the `Throw` and `CrapsGame` leads to another chicken-and-egg design problem. We'll design `Throw` in detail, but provide a rough stub for `CrapsGame`.

Additionally, this chapter will introduce the subtle issue of over-engineering when doing design work. We'll revist these issues a number of times in order to provde examples of good design and the issues that can lead to poor design.

## Overview

The pair of dice can throw a total of 36 unique combinations. These are summarized into fifteen distinct outcomes: the eleven numbers from 2 to 12, plus the four hardways variations for 4, 6, 8 and 10.

In Roulette, the randomized positions on the wheel were called `Bins` and each one had a very simple collection of winning `Outcomes`. In Craps, however, the randomized throws of the dice serve three purposes: they resolve simple one-roll proposition bets, they may resolve hardways bets, and they change the game state (which may resolve game bets). From this we can allocate three responsibilities. We'll look at each of these responsibilities individually.

**One-Throw Propositions.** A `Throw` of the dice includes a collection of proposition `Outcomes` which are immediate winners. This collection will be some combination of 2, 3, 7, 11, 12, Field, Any Craps, or Horn. For completeness, we note that each throw could also contain one of the 21 hop-bet `Outcomes`; however, we'll ignore the hop bets.

**Multi-Throw Propositions.** A `Throw` of the dice may resolve hardways bets (as well as place bets and buy bets). There are three possible conditions for a given throw: some bets may be winners, some bets may be losers, and some bets may remain unresolved. This tells us that a `Throw` may be more than a simple collection of winning `Outcomes`. A `Throw` must also contain a list of losing `Outcomes`. For example, any of the two easy 8 rolls (6-2 or 5-3) would contain winning `Outcomes` for the place-8 bet and buy-8 bet, as well as a losing `Outcome` for a hardways-8 bet. The hard 8 roll (4-4), however, would contain winning `Outcomes` for the place-8 bet, buy-8 bet, and hardways-8 bet

**Game State Change.** Most importantly, a `Throw` of the dice can lead to a state change of the `Game`. This may resolve game-level bets. From the Table 21.1, "Craps Game States", we see that the state changes depend on both the `Game` state plus the kind of `Throw`. The rules identify the following species of `Throw`.

- **Craps.** These are throws of 2, 3 or 12. On a come-out roll, this is an immediate loss. On any other roll, this is ignored. There are 4 of these throws.
- **Natural.** This is a throw of 7. On a come-out roll, this is an immediate win. On any other roll, this is an immediate loss and a change of state. There are 6 of these throws.
- **Eleven.** This is a throw of 11. On a come-out roll, this is an immediate win. On any other roll, this is ignored. There are 2 of these throws.
- **Point.** This is a throw of 4, 5, 6, 8, 9, or 10. On a come-out roll, this estanblishes the point, and

changes the game state. On any other roll, this is is compared against the established point: if it matches, this is a win and a change of game state. Otherwise, it doesn't match and no game state change occurs. There are a total of 24 of these throws, with actual frequencies between three and five.

The state change can be implemented by defining methods in `Game` that match the varieties of `Throw`. We can imagine that the design for `Game` will have four methods: `craps`, `natural`, `eleven`, and `point`. Each kind of `Throw` will call the matching method of `Game`, leading to state changes, and possibly game bet resolution.

The game state changes lead us to design a hierarchy of `Throw` classes to enumerate the four basic kinds of throws. We can then initialize a `Dice` object with 36 `Throw` objects, each of the appropriate subclass. When all of the subclasses have an identical interface, this embodies the principle of polymorphism. For additional information, see Soapbox On Polymorphism.

In looking around, we have a potential naming problem: both a wheel's `Bin` and the dice's `Throw` are somehow instances of a common abstraction. Looking forward, we may wind up wrestling with a deck of cards trying to invent a common nomenclature for all of these randomizers. They create random events, and this leads us to a possible superclass for `Bin` and `Throw`: `RandomEvent`. Currently, we can't identify any features that we can refactor up into the superclass. Rather than over-engineer this, we'll hold off on complicating the design until we find something else that is common between our sources of random events. See the Soapbox on Over-Engineering as a continuation of this rant.

## Soapbox on Over-Engineering

Some of the horror stories of failed OO design projects seem to have over-engineering as the root cause. Over-engineering often includes the creation of superclasses and interfaces to embody *potentially* useful features. We suggest examining all engineering efforts by asking “does it solve a real problem?” Focus on potential value tends to dilute the creation of real value.

We note that software is developed to solve a particular problem. If a design consideration does not help solve the problem as presented, we have to classify the design as potential over-engineering. The most common response to this classification is that we will tend to focus too narrowly and build a *point solution*; the presumption is that point solutions are not as adaptable as something more broadly focused.

Our experience is that when the object design focuses on tangible real-world objects, and models those objects with a high degree of fidelity, these objects are very adaptable; they can be applied to solve a number of real-world problems. When the object design includes a number of irrelevant considerations, it takes too much effort to solve the initial problem, diluting the value of the software.

Additionally, some over-engineering is the result of conflating a number of features into a single class. We prefer to add features slowly so as to clearly separate the various concerns. As an example, it is very easy to conflate `Bet` and `Outcome` into a single class, losing site of the fact that bet amounts can change, but the definition of the outcome itself is invariant.

## Design

There are a number of design elements: the superclass `Throw`, plus the four individual subclasses. From these various kinds of `Throws`, we also have a number of interface methods in a `CrapsGame` class. We'll define a stub class, first, for purposes of testing `Throw`.

### Throw Design

`Throw` is the superclass for the various throws of the dice. Each subclass is a different grouping of the numbers, based on the rules for Craps.

#### Fields

- `Set outcomes ;`

  A collection of one-roll `Outcomes` that win with this throw.

- `int d1 ;`

  One of the two die values, from 1 to 6.

- `int d2 ;`

  The other of the two die values, from 1 to 6.

#### Constructors

-
  ```
  Throw(int d1,
        int d2);
  ```

  Creates this throw. `Outcomes` can be added later.

-
  ```
  Throw(int d1,
        int d2,
        Set outcomes);
  ```

  Creates this throw, and associates the given `Set` of `Outcomes` that are winning propositions.

-
  ```
  Throw(int d1,
        int d2,
        Outcome[] outcomes);
  ```

  Creates this throw, and creates a `Set` of `Outcomes` from the given array of `Outcomes`.

#### Methods

- `boolean hard();`

Returns `true` if `d1` is equal to `d2`. This helps determine if hardways bets have been won or lost.

- `abstract void updateGame(Game theGame);`

  Calls one of the `Game` state change methods: `craps`, `natural`, `eleven`, `point`. This may change the game state and resolve bets.

- An easy-to-read String output method is also very handy. This should return a String representation of the dice. A form that looks like `1,2` works nicely.

## Natural Throw Design

`Natural Throw` is a subclass of `Throw` for the natural number, 7.

### Constructors

-
  ```
  NaturalThrow(int d1,
               int d2);
  ```

  Creates this throw. The arguments `d1+d2` must total 7.

### Methods

- `boolean hard();`

  Returns `false`.

- `abstract void updateGame(Game theGame);`

  Calls the `natural` method of a game `Game`. This may change the game state and resolve bets.

- An easy-to-read String output method is also very handy. This should return a String representation of the dice. A form that looks like `1,2` works nicely.

## Craps Throw Design

`Craps Throw` is a subclass of `Throw` for the craps numbers 2, 3 and 12.

### Constructors

-
  ```
  CrapsThrow(int d1,
             int d2);
  ```

  Creates this throw. The arguments `d1+d2` must total 2, 3 or 12.

### Methods

- `boolean hard();`

  Returns `false`. The numbers 2 and 12 are not part of the hardways bets.

- `abstract void updateGame(Game theGame);`

  Calls the `craps` method of a game `Game`. This may change the game state and resolve bets.

- An easy-to-read String output method is also very handy. This should return a String representation of the dice. A form that looks like `1,2` works nicely.

## Eleven Throw Design

`Eleven Throw` is a subclass of `Throw` for the number, 11.

### Constructors

-
  ```
  ElevenThrow(int d1,
              int d2);
  ```

  Creates this throw. The arguments `d1+d2` must total 11.

### Methods

- `boolean hard();`

  Returns `false`.

- `abstract void updateGame(Game theGame);`

  Calls the `eleven` method of a game `Game`. This may change the game state and resolve bets.

- An easy-to-read String output method is also very handy. This should return a String representation of the dice. A form that looks like `1,2` works nicely.

## Point Throw Design

`Point Throw` is a subclass of `Throw` for the point numbers 4, 5, 6, 8, 9 or 10.

### Constructors

-
  ```
  PointThrow(int d1,
             int d2);
  ```

  Creates this throw. The arguments `d1+d2` must total 4, 5, 6, 8, 9 or 10.

### Methods

- `boolean hard();`

  Returns `true` if `d1` is equal to `d2`. This helps determine if hardways bets have been won or lost.

- `abstract void updateGame(Game theGame);`

  Calls the `point` method of a game `Game`. This may change the game state and resolve bets.

- An easy-to-read String output method is also very handy. This should return a String representation of the dice. A form that looks like `1,2` works nicely.

## Craps Game Design

`CrapsGame` is a preliminary design for the game of Craps. This initial design contains the interface used by the `Throw` class hierarchy to implement game state changes.

### Fields

- `int point = 0;`

  The current point. This will be replaced by a proper **State** design pattern.

### Constructors

- `CrapsGame();`

  Creates this Game. This will be replaced by a constructor that uses `Dice` and `CrapsTable`.

### Methods

- `void craps();`

  Resolves all current 1-roll bets. If the point is zero, this was a come out roll: Pass Line bets are an immediate loss, Don't Pass Line bets are an immediate win. If the point is non-zero, Come Line bets are an immediate loss; Don't Come Line bets are an immediate win. The state doesn't change. A future version will delegate responsibility to the `craps` method of a current state object.

- `void natural();`

  Resolves all current 1-roll bets. If the point is zero, this was a come out roll: Pass Line bets are an immediate win; Don't Pass Line bets are an immediate loss. If the point is non-zero, Come Line bets are an immediate win; Don't Come bets are an immediate loss; the point is also reset to zero because the game is over. Also, hardways bets are all losses. A future version will delegate responsibility to the `natural` method of a current state object..

- `void eleven();`

Resolves all current 1-roll bets. If the point is zero, this is a come out roll: Pass Line bets are an immediate win; Don't Pass Line bets are an immediate loss. If the point is non-zero, Come Line bets are an immediate win; Don't Come bets are an immediate loss. The game state doesn't change A future version will delegate responsibility to the `eleven` method of a current state object..

- `void point(int thePoint);`

  Resolves all current 1-roll bets. If the point is zero, this is a come out roll, and the value of the dice establishes the point. If the point is non-zero and this throw matches the point the game is over: Pass Line bets and associated odds bets are winners; Don't Pass bets and associated odds bets are losers; the point is reset to zero. Finally, if the point is non-zero and this throw does not match the point, the state doesn't change; however, Come point and Don't come point bets may be resolved. Additionally, hardways bets may be resolved. A future version will delegate responsibility to the current state's `point` method to advance the game state.

- An easy-to-read String output method is also very handy. This should return a String representation of the current state. The stub version of this class has no internal state object. This class can simply return a string representation of the point; and the string `"Point Off"` when `point` is zero.

## Deliverables

There are eleven deliverables for this exercise.

- A stub class for `CrapsGame` with the various methods invoked by the throws. The design information includes details on bet resolution that doesn't need to be fully implemented at the present time. For this stub class, the change to the `point` variable is required for unit testing. The other information should be captured as comments and output statements that help confirm the correct behavior of the game.
- The `Throw` superclass, and the four subclasses: `CrapsThrow`, `NaturalThrow`, `ElventThrow`, `PointThrow`.
- Five classes which perform unit tests on the various classes of the `Throw` class hierarchy.

# Chapter 25. Dice Class

### Table of Contents

Unlike Roulette, where a single `Bin` could be identified by the number in the bin, dice use a pair of numbers. In this chapter, we design `Dice`, as well as designing an inner class that is used only to make a single key out of a composite object.

## Overview

The dice have two responsibilities: they are a container for the `Throws` and they pick one of the `Throws` at random.

We find that we have a potential naming problem: both a `Wheel` and the `Dice` are somehow instances of a common abstraction. Looking forward, we may wind up wrestling with a deck of cards trying to invent a common nomenclature for the classes. They create random events, and this leads us to a possible superclass: `Randomizer`. Rather than over-engineer this, we'll hold off on adding this design element until we find something else that is common among them. See Soapbox on Over-Engineering for some additional opinions on this subject.

**Container.** Since the `Dice` have 36 possible `Throws`, it is a collection. We can review our survey of the Java collections in Java Collections and the Python collections in Python Collections for some guidance here. In this case, the choice of `Throw` will be selected by a random numeric index. For Java programmers, this makes the `java.util.Vector` very appealing. Python programmers will find that a `List` will do very nicely.

One consequence of using a `Vector` is deciding how to index each `Throw` available on the dice. In Roulette, we had 36 numbers, starting from 1, plus 0 and 00. By using 37 for the index of the `Bin` that contained 00, each number mapped to the `Bin` index in a simple way. However, for Craps, we have to handle the distinction between hard and easy bets. There will be three instances of the `PointThrows` that contains 4 and 10: two easy instances and one hardways instance. For 6 and 8, there are four easy instances and one hardways instances.

We can't simply add the two dice and use this as an index: this ignores the hardways issue and also loses the important frequency distribution information. For example, there have to be six instances of `SevenThrow`, all of which have dice that sum to 7; but only four instances of `CrapsThrow`, one of which adds to 2, one adds to 12 and the other two add to 3.

In this case, we have two choices. We can rethink our use of a `Vector`: if we use a `Map`, we can use an object representing the pair of numbers as an index instead of a single int value. An alternative is to translate the two dice values into a unique integer from 0 to 35, giving us an index into the `Vector`.

1. If we create a new class to contain each unique pair of integers, we can then use that pair to be the index for a `Map`. The `Dice` class can use this `Map` to associate a `NumberPair` with a `Throw`. The small `NumberPair` class doesn't do very much, except encapsulate the pair of values showing on the dice to create a single object. In Python, a `tuple` does this job nicely, saving us from having to declare a new class.

   Introducing this small class makes the selection of a random `Throw` slightly more complex than simply picking a random integer. Rather than pick a number from 0 to 35, we are either picking a Java `NumberPair` or a Python tuple.

   a. We can pick one of the existing `NumberPair` objects at random from the collection of keys for the `Map` that contains the individual `Throws`. For reference information on this design pattern, see Player Random.
   b. We can create new, random `NumberPair` objects if we override the `equals` and `hashCode` methods of `NumberPair`. We can use these new instances for keys in the `Map`. See On Object Identity for more information on this.

2. We can transform the two numeric dice values to a single index value for the `Vector`. This is a technique called **Key Address Transformation**; we transform the keys into the address (or index) of the data. We can compute the index, $i$, of the `Throw` as follows: $i = 6(d_1-1)+(d_2-1)$. We can reverse this calculation to determine the two dice values that lead to this index. $d_1 = i/6 + 1$, $d_2 = i\%6 + 1$.

Because of encapsulation, the choice of algorithm is completely hidden within the implementation of `Dice`. Our recommendation is the create the small `NumberPair` class to encapsulate the pair of dice, and select `NumberPair` instances from the collection of keys in the `Map`. More advanced students can create a class hierarchy for `Dice` that includes all of the implementations as alternatives.

**Random Selection.** The random number generator in `java.util.Random` helps us locate a `Throw` at random. We will need to get the array or `Collection` of keys in the `Map`. We can use the generator's `public int nextInt(int n);` method to return integers between 0 and and the size of the collection of keys. Then we return the selected `Throw`.

## Design

There are two parts to the dice: a `NumberPair` to represent the numbers on the two faces on a throw the dice, and the `Dice` class which selects a particular throw as the result.

### NumberPair Class

`NumberPair` contains two integers showing the two values on the dice. This is used as the key to the map of pairs of numbers to `Throws`. By overriding `equals` and `hashCode` we don't have to rely on Java's built-in notion of unique identity, but can create any number of distinct objects that will all be correctly equal to each other and return hash codes that match the equality test.

#### Fields

- `int d1 ;`

  Contains the face of one die.

- `int d2 ;`

  Contains the face of the other die.

#### Constructors

- `NumberPair();`

  Creates a new pair of numbers.

### Methods

- `public boolean equals(Object obj);`

  Checks for equality. This is best down by casting the argument to be a `NumberPair` and then comparing d1 and d2 of `this` and the argument's value.

- `public int hashCode();`

  Returns a hashcode. A good hashcode function for two dice is $6(d_1-1)+(d_2-1)$.

## Dice Class

`Dice` contains the 36 individual throws of two dice, plus a random number generator. It can select a `Throw` at random, simulating a throw of the Craps dice.

### Fields

- Java: `java.util.Map throws = new HashMap( 36 );`

  Python: `throws = {}`

  Contains the individual `Throw` instances.

- Java: `java.util.Random rng ;`

  Python: `rng`

  Generates the next random number, used to select a `Throw` from the `throws` collection.

### Constructors

- `Dice();`

  Creates a new random number generator instance, and calls the other constructor (using `this( rng );`).

- `Dice(Random rng);`

  Creates a new set of dice an empty `Map`. Uses the given random number generator instance.

  At the present time, this does not do the full initialization of the `Throws`. We'll rework this in a future exercise.

### Methods

-
  ```
  addOutcome(NumberPair faces,
             Outcome outcome);
  ```

  Adds the given `Outcome` to the `Throw` with the given `NumberPair`. This allows us to create a collection of several one-roll `Outcomes`. For example, a throw of 3 includes four one-roll `Outcomes`: Field, 3, any Craps, and Horn.

-
  ```
  next();
  ```

  Returns the randomly selected `Throw`.

  **Java.** First, get the `Collection` of keys from the `throws`. Be sure to note that the `java.util.Random nextInt` method uses the size of the `throws` collection to return values from 0 to the size of the collection. Typically there are 36 values, numbered from 0 to 35. This randomly selected key will be a `NumberPair`; this is used to get the corresponding `Throw` from the `throws Map`.

  **Python.** The `choice` function will select one of the available `Throws` from the keys of the `throws` map. This tuple is used to return the corresponding `Throw` from the `throws Map`.

-
  ```
  Throw getThrow(int d1,
                 int d2);
  ```

  While not needed by the application, unit tests will need a method to return a specific `Throw` rather than a randomly selected `Throw`. This method takes a particular combination of dice, creates a NumberPair, and returns the appropriate `Throw`.

## Deliverables

There are three deliverables for this exercise. In considering the unit test requirements, we note that we will have to follow the design of the `Wheel` class for convenient testability: we will need a way to get a particular `Throw` from the `Dice`, as well as replacing the random number generator with one that produces a known sequence of numbers.

- The `Dice` class.
- A class which performs a unit test of building the `Dice` class. The unit test should create several instances of `Outcome`, two instances of `Throw`, and an instance of `Dice`. The unit test should establish that `Throws` can be added to the `Dice`.
- A class which performs a demonstration of selecting non-random values from the `Dice` class. By setting a particular seed, the `Throws` will be returned in a fixed order. To discover this non-random order, a demonstration should be built which includes the following.

  1. Create several instances of `Outcome`.

2. Create two instances of `Throw` that use the available `Outcome`s.
3. Create one instance of `Dice` that uses the two `Throw`s.
4. A number of calls to the `next` method should return randomly selected `Throw`s.

Note that the sequence of random numbers is fixed by the seed value. The default constructor for a random number generator creates a seed based on the system clock. If your unit test sets a particular seed value, you will get a fixed sequence of numbers that can be used to get a consistent result.

# Chapter 26. Throw Builder Class

**Table of Contents**

This chapter identifies some subtleties of bets in Craps, and proposes some rather involved design rework to resolve the issues that are raised. Specifically, we didn't allow for an `Outcome` to have odds based on a throw of the dice. We'll need to add this feature carefully.

We'll present two solutions: “Design Heavy” and “Design Light”. While we recommend “Design Heavy”, we find that many programmers and project managers object to the apparent over-engineering of the approach. We have found that it is almost impossible justify the design heavy approach. See our Soapbox on Justification for more on this common blind spot. Instead, we provide the alternative, which will become increasingly unwieldy throughout this part. At some point, we will eventually be forced to adopt the design heavy approach.

We'll present sidebars on the proper design of subclasses and the proper architecture for the packages that make up an application. Additionally, we'll provide a brief FAQ on the design issues raised.

## Soapbox on Justification

It is very difficult to justify design rework. Most managers and designers share a common blind-spot on the amount of evidence required to justify rework. The conversations have the following form.

**Architect.** We need to disentangle Roulette and Craps so that Craps is not a subclass of Roulette. I've got a revised design that will take *X* hours of effort to implement.

**Manager.** I'll need some justification. Why do we have to fix it?

**Architect.** The structure is illogical: Craps isn't a special case of Roulette, they're independent specializations of something more general.

**Manager.** Illogical isn't a good enough justification. Our overall problem domain always contains illogical special cases and user-oriented considerations. You'll have to provide something more concrete.

**Architect.** Okay, in addition to being illogical, it will become too complex: in the future, we'll probably have trouble implementing other games.

**Manager.** How much trouble? Will it be more than *X* hours of effort?

**Architect.** When we include maintenance, adaptation and debugging, the potential future cost is probably larger than *2X* hours of effort. And it's illogical.

**Manager.** Probably larger? We can't justify rework based on probable costs. You'll need something tangible. Will it save us any lines of code?

**Architect.** No, it will add lines of code. But it will reduce maintenance and adaptation costs because it will be more logical.

**Manager.** I conclude that the change is unjustified.

In many cases, we have a manager who's mind is made up and who won't be swayed by facts. This is generally a symptom of an organization that is thinking-impaired. Typically, it is impossible to engage project managers further than this. However, in some cases, conversation continues in the following vein.

**Architect.** Unjustified? Okay, please define what constitutes adequate justification for improvements?

**Manager.** Real savings of effort is the only justification for disrupting the schedule.

**Architect.** And future effort doesn't count?

**Manager.** The probability of savings in the future isn't tangible.

**Architect.** And more logical doesn't count?

**Manager.** If course not; it doesn't result in real schedule savings.

**Architect.** Real schedule savings? That's absurd. The schedule is a notional projection of possible effort. A possible reduction in the possible effort is just as real as the schedule.

**Manager.** Wouldn't it be simpler to...?

For reasons we don't fully understand, a schedule becomes a kind of established fact. Any change to the schedule requires other established facts, not the conjecture of design. For some reason, the idea that the schedule is only a conjecture, based on a previously conjectured design doesn't seem to sway managers from clinging to the schedule. This makes it nearly impossible to justifiy making a design change. The only way to accumulate enough evidence is to make the design change and then measure the impact of the change. In effect, no level of proof can ever override the precedence-setting fact of the schedule.

To continue this rant, the same kind of “inadequate evidence” issue seems to surround all technology changes. We have had conversations like the one shown above regarding object-oriented design, the use of objects in relational databases, the use of object-oriented databases, the use of open-source software, and the use of the star-schema data model for reporting and analysis. For many people, it seems that change can only be considered based on established facts; we observe that these facts can only be established by making a change. While this chicken-and-egg problem is easily resolved by recognizing that the current architecture or schedule is actually *not* an established fact, this is a difficult mental step to take.

As a final complaint, we note that “wouldn't it be simpler” is best described as a *management trump card*. The point is rarely an effort to reduce code complexity, but to promote management understanding of the design. While this is a noble effort, there is sometimes a communication gap between designers and managers. It is incumbent both on designers to communicate fully, and on managers to provide time, budget and positive reinforcement for detailed communication of design considerations and consequences.

## Overview

Enumerating each `Outcome` in the 36 `Throws` could be a tedious undertaking. While it is slightly simpler to hand-code the various combinations, for complete flexibility, we'll design a **Builder** to enumerate all of the `Throws` and their associated list of `Outcomes`. This will build the `Dice`, finishing the elements we deferred from the design of the `Dice` class.

The 36 ways the dice fall can be summarized into 15 kinds of `Throw`, with a fixed distribution of probabilities. We could develop a **Builder** class that enumerates the 36 individual `Throws`, assigning the appropriate attribute values to each object. An alternative is for a **Builder** class to step through the 15 kinds of `Throw`, creating the proper number of instances of each kind. It seems slightly simpler to examine each pair of dice and determine which kind of `Throw` to build.

There are eight one-roll `Outcomes` that need to be assigned to the various `Throw` instances we are building. We will share references to the following `Outcome` objects among the `Throws`:

- The number 2, with 30:1 odds.
- The number 3, with 15:1 odds.
- The number 7, with 4:1 odds.
- The number 11, with 15:1 odds.
- The number 12, with 30:1 odds.
- The “any craps” outcome, with 7:1 odds. This belongs to throws for 2, 3 and 12.
- The “horn” outcome, with two sets of odds. This belongs to throws for 2, 3, 11 and 12. For 2 and 12, the odds are 27:4; for 3 and 11, the odds are 3:1.
- The “field” outcome, with two sets of odds. This belongs to throws for 2, 3, 4, 9, 10, 11 and 12. For 2 and 12, this pays 2:1, all others pay even money (1:1).

We can use the following algorithm for building the `Dice`.

**Procedure 26.1. Building Dice**

- **For All Faces Of Die 1.** For $d_1$ in the range 0 to 5
    a. **For All Faces Of A Die 2.** For $d_2$ in the range 0 to 5
        i. **Sum the Dice.** Compute the sum, $s$, as $d_1$+$d_2$+2.
        ii. **Craps?** If $s$ is in 2, 3, and 12, we create a `CrapsThrow` instance. This will include a reference to one of the 2, 3 or 12 `Outcomes`, plus references to the Any Craps, Horn and Field `Outcomes`.
        iii. **Point?** For $s$ in 4, 5, 6, 8, 9, and 10 we will create a `PointThrow` instance.
            A. **Hard?** When $d_1 = d_2$, this is a *hard* 4, 6, 8 or 10.
            B. **Easy?** Otherwise, this is an *easy* 4, 6, 8 or 10.
            C. **Field?** For $s$ in 4, 9 and 10 we include a refrence to the Field `Outcome`.
        iv. **Natural?** For $s$ of 7, we create a `NaturalThrow` instance. This will also include a reference to the 7 `Outcome`.
        v. **Eleven?** For $s$ of 11, we create an `ElevenThrow` instance. This will include references to the 11, Horn and Field `Outcomes`.

Our detailed examination of the bets has turned up an interesting fact about Field bets and Horn bets: these bets also have payoffs that depend on the number on the dice. In our earlier analysis of `Outcome`, we missed this nuance, and did not provide for a `winAmount` method that depends on the `Dice`. We'll present the solution to this as a fairly formal procedure that we find helps to resolve these kind of design issues.

**Problem Statement.** Unlike the Pass Line and Come Line bets, Field bets and Horn bets have payoffs that depend on the number on the dice. These bets are not moved to a new `Outcome` when the point is established. How do we compute the win amount for Field and Horn bets?

**Context.** Our design objective is to have a `Bet` reference a single `Outcome` object. The `Bet` is compared with a `Set` of winning `Outcomes`. We'd like to have a single horn `Outcome` object and field `Outcome` object shared by multiple instances of `Throw` to make this comparison work in a simple, general way. As an example, the player can place a bet on the Field `Outcome`, which is shared by all of the field numbers (2, 3, 4, 9, 10, 11, 12). The problem we have is that for 2 and 12, the outcome pays 2:1 and for the other field numbers it pays 1:1, and our design only has a single set of payout odds.

**Forces.** In order to handle this neatly, we have two choices. One choice is to have two `Outcomes` bundled into a single bet. This allows us to create a `Bet` that includes both the low-odds field outcome (3, 4, 9, 10 and 11) plus the high-odds field outcome (2 and 12). One of the nice features of this is that it is a small expansion to `Bet`. However, further research shows us that there are casino-specific variations on the field bet, including the possibility of three separate `Outcomes` for those casinos that pay 3:1 on 12. This makes construction of the `Bet` rather complex, and dilutes the responsibility for creating a proper `Bet`. Once we put multiple `Outcomes` into a `Bet`, we need to assign responsibility for keeping the bundle of Field `Outcomes` together.

Pursuing this further, we could expand `Outcome` to follow the **Composite** design pattern. We could introduce a subclass which was a bundle of multiple `Outcomes`. This would allow us to keep `Bet` very simple, but we still have to construct appropriate composite `Outcome` instances for the purpose of creating `Bets`. Rather than dive into allocating this responsibility, we'll look at other alternatives, and see if something turns up that doesn't add as much complexity.

Another approach is to add an additional method to `Outcome` that calculates the win amount given the current `Throw`. This allows us to have a single Field `Outcome` with different odds for the various numbers in the field. This further allows us to create slightly different Field `Outcome` class definitions for the casino-specific variations on the rules.

**Solution.** Our first design decision, then, is to add an additional method to `Outcome` that calculates the win amount given the current `Throw`.

**Consequences.** There are a number of consequences of this design decision. The next design problem we have to solve is where in the `Outcome` class hierarchy do we add this additional `winAmount` method? After that, we will need to determine the signature of the revised `winAmount` method. This leads us to two rounds of additional problem-solving.

**Consequent Problem: Class Hierarchy.** While it appears simplest to add a “variable odds” subclass with a new method that uses the number on the dice, we find that this is impractical. Our design depends on polymorphism of the `Outcome` class: all instances have the same interface. In order to maintain this polymorphism, we need to add this new method to the superclass. The superclass version of the new winAmount based on the Craps Throw can return an answer computed by the original winAmount method. We can then override this in a subclass for Field and Horn bets in Craps.

The alternative is to break polymorphism and create a Craps-specific Outcome subclass. This would ripple out to Throw, Bet, Table, Player. This is an unpleasant cascade of change, easily avoided by assuring that the Outcome class hierarchy is polymorphic.

Our second design decision is to insert this at the top of the Outcome class hierarchy, and override this new winAmount method in the subclasses that we use to create horn and field Outcomes.

The Horn bet's winAmount method applies one of two odds, based on the event's value. The Field bet may have any of two or three odds, depending on the casino's house rules. It is difficult to identify a lot of commonality between Horn bets and Field bets. Faced with these irreconcilable differences, we will need two different winAmount methods, leading us to create two subclasses: OutcomeField and OutcomeHorn.

## Caution

The differences are minor, merely a list of numbers and odds. However, our design objective is to minimize if-statements. We prefer many simple classes over a single class with even a moderately complex method. Complex methods are often a habit left-over from a background in procedural programming; we prefer to challenge those mental habits.

**Consequent Problem: Method Signature.** The OutcomeField and OutcomeHorn classes both implement versions of the winAmount method that determines the odds based on the total of the two dice. This total is the only value we need from a Throw object, and is an easy method to add to the Throw class.

Our third design decision is to define an additional winAmount method that determines the odds based on the total of the two dice and computes the appropriate amount. The superclass versions of both winAmount methods compute the same result. For the Roulette game Outcomes, the new winAmount method will not be used. In the Craps game, however, we will use this new method for evaluating all Bets.

**Other Consequences.** This change to Outcome leads to consider possibly designing a common superclass for Throw and Bin. Since we used an integer value to identify each Roulette Bin as well as the total of the Craps Throw, we could factor this integer value up into a superclass for both Throw and Bin. We could call the parent class a RandomEvent. This new class would have an integer event identifier: either the wheel's bin number or the total of the two dice. Given this new superclass, we could then rearrange both Throw and Bin to be subclasses of RandomEvent. This would also force us to rework parts of Wheel that creates the Bins.

A benefit of creating a RandomEvent class hierarchy is that we can change the new winAmount method to compute the win amount given a RandomEvent instead of a highly Craps-specific Throw. This makes the winAmount method far more generally useful, and keeps Craps and Roulette separate from each other.

This technique of reworking Throw and Bin to be subclasses of a common superclass is a fairly common kind of *generalization refactoring*. We observe that more experienced designers develop an ability to locate this kind of very focused commonality. On the other hand, less experienced designers do not focus well and tend to conflate too many nearly-common features into a single class, leading to a brittle design that cannot easily be reworked. In our example, we considered lifting one common attribute to the superclass so that a related class (`Outcome`) could operate on instances of these two classes in a uniform manner. For more information on this rework, see Soapbox on Subclasses.

### Soapbox on Subclasses

Designers new to OO techniques are sometimes uncomfortable with the notion of highly-specialized subclasses. We'll touch on two reasons why specialized subclasses are far superior to the alternatives.

One approach to creating common features is to add nested if-statements instead of creating subclasses. In our example, we might have elected to add if-statements that would determine if this was a variable-odds outcome, and then determine which of the available odds would be used. The first test (for being a variable-odds outcome) is, in effect, a determination of the subclass of `Outcome`. Since an object's membership in a class determines the available methods, there's no reason to *test* for membership. In most cases, a test for membership in a class is also done at construction time. If we use that initial decision to select the subclass (with appropriate subclass-specific methods) we do not repeat that decision every time a method is invoked. This is the efficiency rationale for introducing a subclass to handle these special cases.

The more fundamental reason is that specialized subclasses usually represent distinct kinds of real-world things, which we are modeling in software-world. In contrast, a procedural view-point is that the variant behavior is a special case: a condition or situation that requires unique processing. This view often confuses the implementation of the special case (via an if-statement) with the nature of the specialization. In our case, we have a number of distinct things, some of which are related because they have common attributes and behavior. The `Outcome` is fairly intangible, so the notion of commonality can be difficult to see. Contrast this with `Dice` and `Wheel`, which are tangible, and are obviously different things, however they have common behavior and a common relationship with a casino game.

Sometimes it helps to visualize this by getting pads of different-colored sticky paper, and making a mockup of the object structure on whiteboard. Each class is represented by a different color of paper. Each individual object is an individual slip of sticky paper. To show the relationship of `Dice`, `Throw` and `Outcome`, we draw a large space on the board for an instance of `Dice` which has smaller spaces for 36 individual `Throws`.

In one `Throw` instance, we put a sticky for `Outcomes` 2, Field, Horn, and Any Craps. We use three colors of stickies to show that 2 and Any Craps are ordinary `Outcomes`, Field is one subclass and Horn is another subclass.

In another `Throw` instance, we put a sticky for `Outcome` 7, using the color of sticky for ordinary `Outcomes`.

This can help to show what the final game object will be examining to evaluate winning bets. The game object will have a list of winning `Outcomes` and bet `Outcomes` actually on the table. When a 2 is thrown, the game process will pick up each of the stickies, compare the winning `Outcomes` to the bets, and then use the method appropriate to the color of the sticky when computing the results of the bet.

We will present two alternative designs paths: minimal rework, and a design that is at the fringe of over-engineering. The minimal design effort has one unpleasant consequence: Roulette's `Outcome` instances depend on the Craps-related `Throw` class. This leads to an entanglement between Roulette and Craps around a feature that is really a special case for Craps only. This kind of entanglement may limit our ability to successfully reuse these classes. See Soapbox on Architecture for a discussion on this issue. The possible over-engineering prevents this entanglement. We consider this separation very desirable, even in an application as small as this exercise.

## Soapbox on Architecture

There are a number of advanced considerations behind the Design Heavy section. This is a digression on architecture and *packages of classes*. While this is beyond the basics of OO design, it is a kind of justification for the architecture we've chosen.

A good design balances a number of forces. One example of this is our use of a class hierarchy to decompose a problem into related class descriptions, coupled with the collaboration among individual objects to compose the desired solution. The desired behavior emerges from this tension between decomposition of the class design and composition of the objects to create the desired behavior.

Another example of this decomposition is the organization of our classes into packages. We have, in this book, avoided discussion of how we package classes. It is a more subtle aspect of a good design, consequently we find it challenging to articulate sound principles behind the layers and partitions of a good collection of packages. There are some design patterns that give us packaging guidance, however.

One packaging pattern is the ***5-Layer Design*** that encourages us to separate our design into *layers* of *view*, *control*, *model*, *access* and *persistence*. For our current application, the view is the output log written to `System.out`, the control is the overall main method and the `Simulation` class, the model is the casino game model. We don't have any data access or data persistence issues, but these are often implemented with *JDBC* and a *relational database*.

While one of the most helpful architectural patterns, this version of the **5-Layer Design** still leaves us with some unsatisfying gaps. For example, common or *infrastructure* elements don't have a proper home. They seem to form another layer (or set of layers). Further, the model layer often decomposes into domain elements, plus elements which are specializations focused on unique features of the business, customer, vendor or product.

Another packaging pattern is the >**Sibling Partition**, which encourages us to separate our application-specific elements to make them parallel *siblings* of a superclass so that we can more easily add new applications or remove obsolete applications. In this case, each casino game is a separate application of our casino game simulator. At some point, we may want to isolate one of the games to reuse just the classes of that game in another application. By making the games proper siblings of each other, and children of an abstract parent, they can be more easily separated.

Applying these layered design and application partitioning design patterns causes us to examine our casino game model more closely and further sub-divide the model into game-specific and game-independent elements. If necessary, we can further subdivide the general elements into those that are part of the *problem domain* (casino games) and those that are even more general *application infrastructure* (e.g., simulation and statistics). Our ideal is to have a tidy, short list of classes that provides a complete game simulation. We can cut our current design into three parts: Roulette, Craps and application infrastructure. This allows us to compose Roulette from the Roulette-specific classes and the general infrastructure classes, without including any of the Craps-specific classes.

The following architecture diagram captures a way to structure the packages of these applications.

| | |
|---|---|
| Simulator, Statistics | |
| Craps Player hierarchy | Roulette Player hierarchy |
| Craps Game, Table, Dice, Throw | Roulette Game, Table, Wheel, Bin |
| Outcome, RandomEvent, Bet, Player, any other superclasses | |

Our class definitions have implicitly followed this architecture, working from general to game- and player-specific classes. Note that our low-level classes evolved through several increments. We find this to be superior to attempting to design the general classes from the outset: it avoids any over-engineering of the supporting infrastructure. Additionally, we we careful to assure that our top-level classes contain minimal processing, and are are compositions of lower-level object instances.

A very good design could carefully formalize this aspect of the architecture by assuring that there are minimal references between layers and partitions, and all references are “downward” references from application-specific to general infrastructure packages. In our case, the Simulator should have access only to Player and Game layers. Two Game partitions should be separate. Finally, we would like to assure that the Player and Game don't have invalid “upward” references to the Simulator. There are some tools that can enforce this architectural separation aspect of the design. Lacking tools, we need to exercise some discipline to honor the layers and partitions.

## Questions and Answers

Q: Why is do we need RandomEvent? Isn't this overengineering?
Q: Didn't we notice the need for this RandomEvent class back in ? Why was it a bad idea then and a good idea now?
Q: Isn't the goal to leave Roulette alone? Isn't the ideal to extend the design with subclasses, leaving the original design in place?

**Q:** Why is do we need `RandomEvent`? Isn't this overengineering?

**A:** Clean separation between Craps and Roulette isn't necessary, but is highly desirable. We prefer not to have Roulette classes depend in any way on Craps classes. Instead of having them entangled, we factor out the entanglement and make a new class from this. This is also called reducing the coupling between classes. We prefer the term “entanglement” because it has a suitably negative connotation.

**Q:** Didn't we notice the need for this `RandomEvent` class back in Soapbox on Over-Engineering? Why was it a bad idea then and a good idea now?

**A:** Some experienced designers immediately notice this kind of commonality between `Throw` and `Bin`, and can handle it without getting badly side-tracked. However, some beginning designers can spend too much time searching for this kind of commonality. We've seen examples of improper factoring where classes were combined in an early phase of design, only to lead to expensive rework when distinctions were uncovered later, invalidating large parts of the design. We prefer to wait until we are sure we've understood the problem and the solution before committing to a particular class design.

**Q:** Isn't the goal to leave Roulette alone? Isn't the ideal to extend the design with subclasses, leaving the original design in place?

**A:** Yes, the goal is to extend a design via subclasses. But, this is only possible if the original design is suitable for extension by subclassing. We find that it is very difficult to create a design that both solves a problem and can be extended to solve a number of related problems.

Note that a general, extensible design has two independent feature sets. On one level it solves a useful problem. Often, this is a difficult problem in its own right, and requires considerable skill merely to ferret out the actual problem and craft a usable solution within budget, time and skill constraints.

On another, deeper level, our ideal design can be extended. This is a different kind of problem that requires us to consider the various kinds of *design mutations* that may occur as the software is maintained and adapted. This requires some in-depth knowledge of the problem domain. We need to know how the current problem is a specialization of other more general problems. We also need to note how our solution is only one of many solutions to the current problem. We have two dimensions of generalization: problem generalization as well as solution generalization.

Our initial design for roulette just barely provided the first level of solution. We didn't make any effort to plan for generalization. The “Design Heavy” solution generalizes Roulette to make it more suitable for Craps, also. Looking forward, we'll have to make even more adjustments before we have a very tidy, general solution.

## Design Light

In order to get the Craps game to work, we can minimize the amount of design. This minimal rework is a revision to `Outcome`, the two subclasses of `Outcome` (`OutcomeField`, and `OutcomeHorn`), and the initializer for `Dice`.

This minimal design effort has one unpleasant consequence: Roulette's `Outcome` instances will depend on the Craps-specific `Throw` class. This entangles Roulette and Craps around a feature that is really a special case for Craps only. This kind of entanglement often limits our ability to successfully package and reuse these classes.

### Outcome Rework

The class `Outcome` needs a method to compute the win amount based on a `Throw`.

In Java, we can use an overloaded method name for the two version of `winAmount`. In Python, we use optional parameters to achieve the same degree of flexibility. Developers new to Java can see Java Overloaded Methods on overloaded methods for more information on this important technique. Developers new to Python can see Python Overloaded Method.

-
  ```
  double winAmount(int amount,
                   Throw event);
  ```

  Returns the product this `Outcome`'s odds numerator by the given amount, divided by the odds denominator.

  In the rare case of craps Horn bet and Field bets, a subclass will override this method to check the specific value of the `event` and compute appropriate odds.

## OutcomeField Design

`OutcomeField` contains a single outcome for a field bets that has a number of different odds, and the odds used depend on a `RandomEvent`.

### Methods

- `double winAmount(int amount);`

  In Python, this method should raise the `NotImplementedException`. In Java, this method can throw the `NoSuchMethedException`. This method should not be called for this kind of outcome; any attempt to do so is a serious design error.

-
  ```
  double winAmount(int amount,
                   Throw event);
  ```

  Checks the event to locate the correct odds. Returns the product of the appropriate odds numerator by the given amount, divided by the odds denominator.

- An easy-to-read String output method is also very handy. This should return a String representation of the name and the odds. A form that looks like `Field (1:1, 2 and 12 2:1)` works nicely.

## OutcomeHorn Design

`OutcomeHorn` contains a single outcome for a Horn bet that has a number of different odds, and the odds used depend on a `RandomEvent`.

### Methods

- `double winAmount(int amount);`

  In Python, this method should raise the `NotImplementedException`. In Java, this method can throw the `NoSuchMethedException`. This method should not be called for this kind of outcome; any attempt to do so is a serious design error.

-
  ```
  double winAmount(int amount,
                   Throw event);
  ```

  Checks the event to locate the correct odds. Returns the product of the appropriate odds numerator by the given amount, divided by the odds denominator.

- An easy-to-read String output method is also very handy. This should return a String representation of the name and the odds. A form that looks like `Horn (27:4, 3:1)` works nicely.

## ThrowBuilder class

`ThrowBuilder` initializes the 36 `Throws`, each initialized with the appropriate `Outcomes`. Subclasses can override this to reflect different casino-specific rules for odds on Field bets.

### Constructors

- `ThrowBuilder();`

  Initializes the ThrowBuilder.

### Methods

- `buildThrows(Dice theDice);`

  Creates the 8 one-roll `Outcome` instances (2, 3, 7, 11, 12, Field, Horn, Any Craps). It then creates each of the 36 `Throws`, each of which has the appropriate combination of `Outcomes`. The `Throws` are assigned to *`theDice`*.

## Design Heavy

In order to produce a solution that has a better architecture with more reusable components, we need to do some additional generalization. This design effort disentangles Roulette and Craps; they will not share the `Throw` class that should only be part of Craps. Instead, the highly reused `Outcome` class depends only on a new superclass, `RandomEvent`, which is not specific to either game.

Given the new generalization, `RandomEvent`, we can rework the `Outcome` to use this for computing win amounts. We will have to rework `Bin`, `Wheel`, and `Throw` to make proper use of this new superclass. We can then create the craps-specific subclasses (`OutcomeField`, and `OutcomeHorn`), and the initializer for `Dice`.

## RandomEvent class

The class `RandomEvent` is the superclass for the random events on which a player bets. This includes `Bin` of a Roulette wheel and `Throw` of Craps dice.

### Fields

- `int event ;`

  Contains an integer identifier for this event. This is an index into the Vector of events maintained by the container (either the Wheel or the Dice).

### Constructors

- `RandomEvent(int event);`

  This saves the event identifier in `event`.

## Bin and BinBuilder Rework

**Bin rework.** The class `Bin` needs to be a subclass of `RandomEvent`. This changes the constructors of `Bin` as follows.

- `Bin(int event);`

  Creates an empty `Bin`; uses the `super()` statement to invoke superclass constructor. `Outcomes` can be added to it later.

-
  ```
  Bin(int event,
      Outcome[] outcomes);
  ```

  Creates an empty `Bin` using the `this()` statement to invoke the default constructor. It then loads that collection using elements of the given array.

-
  ```
  Bin(int event,
      Collection outcomes);
  ```

  Creates an empty `Bin` using the `this()` statement to invoke the default constructor. It then loads that collection using an iterator over the given `Collection`. This relies on the fact that all classes that implement `Collection` will provide the `iterator`; the constructor can convert the elements of the input collection to a proper `Set`.

**BinBuilder Rework.** The class `BinBuilder` creates the individual `Bin` instances. This class will need to provide the numeric identifier to the `Bin` constructor when doing initialization.

## Dice and Wheel Rework

We will continue to treat `Wheel` and `Dice` as separate classes. They appear to have some common features, but there does not appear to be enough commonality to unify them into a class hierarchy.

**Wheel Rework.** The class `Wheel`, which contains the individual `Bin` instances, can use the numeric identifier as an index into the `Vector` or `list` of `Bins`. This is a change to the `addOutcome` method.

**Dice Rework.** The class `Dice`, which contains the individual `Thorow` instances, can use a numeric identifier as an index into the `Vector` or `list` of `Throws`. This is a change to the `addOutcome` method.

Which class contains the information necessary to transform the pair of dice into a numeric value? Clearly, the responsibility belongs to the internal class `NumberPair`. We will add a `index` method to `NumberPair`, which returns the integer index based on the two dice values.

## Throw Rework

The class `Throw` needs to be a subclass of `RandomEvent`. This changes one constructors of `Throw`.

-
  ```
  Throw(int d1,
        int d2);
  ```

  Creates this throw. The superclass promises a single numeric code in the variable `event`. This is computed from the two dice values as follows: $6(d_1\text{-}1)+(d_2\text{-}1)$. After basic construction, the various `Outcomes` can be added later.

## Outcome Rework

The class `Outcome` needs a method to compute the win amount based on a `RandomEvent`.

In Java, we can use an overloaded method name for the two version of `winAmount`. In Python, we use optional parameters to achieve the same degree of flexibility.

-
  ```
  double winAmount(int amount,
                   RandomEvent event);
  ```

  Returns the product this `Outcome`'s odds numerator by the given amount, divided by the odds denominator.

  In the rare case of craps horn bet and field bets, a subclass will override this method to check the random event and compute appropriate odds.

## OutcomeField Design

`OutcomeField` contains a single outcome for a Field bet that has a number of different odds, which depend on the `Throw`.

### Methods

-
  ```
  double winAmount(int amount);
  ```

  In Python, this method should raise the `NotImplementedException`. In Java, this method can throw the `NoSuchMethedException`. This method should not be called for this kind of outcome; any attempt to do so is a serious design error.

- `double winAmount(int amount,`
  `                  Throw event);`

  Checks the `Throw` to locate the correct odds. Returns the product of the appropriate odds numerator by the given amount, divided by the odds denominator.

- An easy-to-read String output method is also very handy. This should return a String representation of the name and the odds. A form that looks like `Field (1:1, 2 and 12 2:1)` works nicely.

## OutcomeHorn Design

`OutcomeHorn` contains a single outcome for a Horn bet that has a number of different odds, which depend on the `Throw`.

### Methods

- `double winAmount(int amount);`

  In Python, this method should raise the `NotImplementedException`. In Java, this method can throw the `NoSuchMethedException`. This method should not be called for this kind of outcome; any attempt to do so is a serious design error.

- `double winAmount(int amount,`
  `                  Throw event);`

  Checks the `Throw` to locate the correct odds. Returns the product of the appropriate odds numerator by the given amount, divided by the odds denominator.

- An easy-to-read String output method is also very handy. This should return a String representation of the name and the odds. A form that looks like `Horn (27:4, 3:1)` works nicely.

## ThrowBuilder class

`ThrowBuilder` initializes the 36 `Throw`s, each initialized with the appropriate `Outcome`s. Subclasses can override this to reflect different casino-specific rules for odds on Field bets.

### Constructors

- `ThrowBuilder();`

  Initializes the ThrowBuilder.

### Methods

- `buildThrows(Dice theDice);`

  Creates the 8 one-roll `Outcome` instances (2, 3, 7, 11, 12, Field, Horn, Any Craps). It then creates each of the 36 `Throws`, each of which has the appropriate combination of `Outcomes`. The `Throws` are assigned to *`theDice`*.

## Deliverables

There are eight deliverables for the light version of this exercise.

- Rework the `Outcome` class to add the new `winAmount` method that uses a `RandomEvent`.
- Rework the `Outcome` class unit test to exercise the new `winAmount` method that uses a `Throw`. For all current subclasses of `Outcome`, the results of both versions of the `winAmount` method produce the same results.
- Create the `OutcomeField` class.
- Create a unit test for the `OutcomeField` class. Two instances of `Throw` are required: a 2 and a 3. This should confirm that there are different values for `winAmount` for the two different `Throw` instances.
- Create the `OutcomeHorn` class.
- Create a unit test for the `OutcomeHorn` class. Two instances of `Throw` are required: a 2 and a 3. This should confirm that there are different values for `winAmount` for the two different `Throw` instances.
- Create the `ThrowBuilder`. This was our objective, after all.
- Rework the unit test of the `Dice` class. The unit test should create and initialize a `Dice`. It can use the `getThrow` method to check selected `Throws` for the correct `Outcomes`.

There are twelve deliverables for the heavy version of this exercise. This version involves significant rework, but produces a more general version of `Outcome` and separates Craps from Roulette.

- Create the `RandomEvent` class.
- Rework the `Bin` class to be a subclass of `RandomEvent`. The existing unit tests for `Bin` should continue to work correctly.
- Rework the `Wheel` class to use the new constructors for `Bin`. The existing unit tests for `Wheel` should continue to work correctly.
- Rework the `Throw` class to be a subclass of `RandomEvent`. The existing unit tests should continue to work correctly.
- Rework the `Outcome` class to add the new `winAmount` method that uses a `RandomEvent`.
- Rework the `Outcome` class unit test to exercise the new `winAmount` method that uses a `RandomEvent`. For all current subclasses of `Outcome`, the results of both versions of the `winAmount` method produce the same results.

- Create the `OutcomeField` class.
- Create a unit test for the `OutcomeField` class. Two instances of `Throw` are required: a 2 and a 3. This should confirm that there are different values for `winAmount` for the two different `Throw` instances.
- Create the `OutcomeHorn` class.
- Create a unit test for the `OutcomeHorn` class. Two instances of `Throw` are required: a 2 and a 3. This should confirm that there are different values for `winAmount` for the two different `Throw` instances.
- Rework the `NumberPair` to reduce the pair of dice to a numeric index. Rework the `Dice` class to use the numeric index information.
- Create the `ThrowBuilder`. This was our objective, after all.
- Rework the unit test of the `Dice` class. The unit test should create and initialize a `Dice`. It can use the `getThrow` method to check selected `Throws` for the correct `Outcomes`.

The correct distribution of throws is as follows. This information will help confirm the results of `ThrowBuilder`.

| Throw | Frequency |
|---|---|
| 2 | 1 |
| 3 | 2 |
| easy 4 | 2 |
| hard 4 | 1 |
| 5 | 4 |
| easy 6 | 4 |
| hard 6 | 1 |
| 7 | 6 |
| easy 8 | 4 |
| hard 8 | 1 |
| 9 | 4 |
| easy 10 | 2 |
| hard 10 | 1 |
| 11 | 2 |
| 12 | 1 |

# Chapter 27. Bet Class

### Table of Contents

This chapter will examine the `Bet` class, and its suitability for the game of Craps. We'll expand the design to handle additional complications present in real casino games.

## Overview

A `Bet` is an amount that the player has wagered on a specific `Outcome`. This is a simple association of an amount, an `Outcome`, and a specific `Player`.

When considering the various line bet outcomes (Pass Line, Come Line, Don't Pass and Don't Come), we noted that when a point was established the bet was either a winner or a loser, or it was moved from the line to a particular number based on the throw of the dice. We'll need to add this responsibility to our existing definition of `Bet`. This responsibility can be implemented as a `setOutcome` method that leaves the amount intact, but changes the `Outcome` from the initial Pass Line or Come Line to a specific point outcome.

A complexity of placing bets in Craps is the commission (or vigorish) required for Buy bets and Lay bets. This is a 5% fee, in addition to the bet amount. A player puts $21 down, which is a $20 bet and a $1 commission. We'll need to add a a commission or vig responsibility to our definition of `Bet`.

This price to place a bet generalizes nicely to all other bets. For most bets, the price is simply the amount of the bet. For Buy bets, the price is 5% higher than the amount of the bet; for Lay bets, the price depends on the odds. This adds a new method to `Bet` that computes the price of the bet. This has a ripple effect throughout our `Player` hierarchy to reflect this notion of the price of a bet. We will have to make a series of updates to properly deduct the price from the player's stake instead of deducting the amount of the bet.

## Design

There are two parts to creating a proper Craps bet: a revision of the base `Bet` to separate the price from the amount bet, and a `CommissionBet` subclass to compute prices properly for the more complex Craps bets.

### Bet Rework

`Bet` associates an amount and an `Outcome`. The `Game` may move a `Bet` to a different `Outcome` to reflect a change in the odds used to resolve the `Bet`. In a future round of design, we can also associate a it with a `Player`.

#### Methods

- `void setOutcome(Outcome outcome);`

Sets the `Outcome` for this bet. This has the effect of moving the bet to another `Outcome`.

- `double price(int amount);`

  Computes the price for this bet. For most bets, the price is the amount. Subclasses can override this to handle buy and lay bets where the price includes a 5% commission on the potential winnings.

### CommissionBet

`CommissionBet` is a `Bet` with a commission payment (or vigorish) that determines the price for placing the bet.

#### Fields

- `double vig = 0.05;`

  Holds the amount of the vigorish. This is almost universally 5%.

#### Methods

- `double price(int amount);`

  Computes the price for this bet. There are two variations: Buy bets and Lay bets.

  A Buy bet is a right bet; it has a numerator greater than or equal to the denominator (for example, 2:1 odds, which risks 1 to win 2), the price is 5% of the amount bet. A $20 Buy bet has a price of $21.

  A Lay bet is a wrong bet; it has a denominator greater than the numerator (for example, 2:3 odds, which risks 3 to win 2), the price is 5% of 2/3 of the amount. A $30 bet Layed at 2:3 odds has a price of $31, the $30 bet, plus the vig of 5% of $20 payout.

## Deliverables

There are three deliverables for this exercise.

- The revised `Bet` class.
- The new `CommissionBet` subclass. This computes a price that is 5% of the bet amount.
- A class which performs a unit test of the various `Bet` classes. The unit test should create a couple instances of `Outcome`, and establish that the `winAmount` and `price` methods work correctly. It should also reset the `Outcome` associated with a `Bet`

We could rework the entire `Player` class hierarchy for Roulette to compute the `Bet`'s price in the `placeBets`, and deduct that price from the player's stake. For Roulette, however, this subtlety is over-engineering, as no bet has a commission.

# Chapter 28. CrapsTable Class

**Table of Contents**

In Roulette, the table was a largely passive repository for `Bets`. In Craps, however, the table and game must collaborate to accept or reject bets based on the state of the game. This validation includes rules based on the total amount bet as well as rules for the individual bets.

In Chapter 24, *Throw Class*, we roughed out a stub version of `CrapsGame` that could be used to test `Throw`. In this section, we will extend this stub with additional features required by the table.

## Overview

The `Table` is where the `Bets` are placed. The money placed on `Bets` on the `Table` is "at risk"; these bets either win an amount based on the odds, or lose the amount placed by the player. The Don't Come and Don't Pass bets may be returned, called a "push". The Buy and Lay bets include a commission (or vigorish) to place the bet; the commission is lost money; the balance of the bet, however, may win or lose. The responsibility for a push is something we can allocate to `Game`, the commission belongs to `Bet`.

Some `Bets` (specifically Pass, Don't Pass, Come and Don't Come) can have their `Outcome` changed. The bet is created with one `Outcome`. That bet may be resolved as an immediate winner or loser; alternatively, the `Bet` may be changed to a new `Outcome`, possibly with different odds. In a casino, the chips initially placed on Come Line and Don't Come bets are relocated to a point number box to show this change. In the case of Pass Line and Don't Pass bets, the "On" marker is placed on the table to show an implicit movement of all of those line bets. The change is the responsibility of the `Game`; however, the `Table` must provide an iterator over the line bets that the `Game` will move.

Each change to the game state changes the allowed bets as well as the active bets. When a point is off, most of the bets on the table are not allowed, and some others are inactive, or not "working". When a point is established, all bets are allowed, and all bets are active. We'll examine the rules in detail, below. The `Table` must be able to reject bets which are inappropriate for the current `Game` state.

These new responsibilities (changing `Bets`, inactivating bets and rejecting bets based on `Game` state), require additional collaboration between `Game` and `Table`. We will have to add methods to `CrapsGame` that will allow or deny some bets, as well as methods that will active or deactive some bets.

We have to choose where in the class hierarchy we will retrofit this additional collaboration. Should we put this at a high-enough level to add this to the `Table` class used for Roulette? If we do add this for Roulette, we could simply return `true` from the method that validates the allowed bets, since all bets are allowed in Roulette. However, our overall application design does not depend on all subclasses of `Game` and `Table` being polymorphic; we will never mix and match different combinations of Craps Table and Roulette Game. Because we don't need polymorphism, we can create a subclass of `Table` with a more complex interface and leave Roulette untouched. Perhaps we'll call it `CrapsTable`.

After deciding to create a `CrapsTable` subclass, we have several consequent decisions. First, we turn the interesting question of how best to allocate responsibility for keeping the list of `Outcomes` which change with the game state. We can see three places to place this responsibility.

1. We could make `CrapsTable` responsible; it could have methods to return the lists of `Outcomes` that are allowed or not allowed. `CrapsGame` can make a call to get the list of `Outcomes` and make the changes. Making each change would involve the `CrapsTable` a second time to mark the individual `Outcomes`. This information is then used by the `CrapsTable` to validate individual `Bets`.

2. We could `CrapsGame` responsible; it could invoke a method of `CrapsTable` that changes a single `Outcome`'s state to makt it inactive. This information is then used by the `CrapsTable` to validate individual `Bets`.

3. An appealing choice is to have the `validBet` method of `CrapsTable` depend on `CrapsGame` to determine which bets are allowed or denied. In this case, `CrapsGame` has the responsibility to respond to requests from either `CrapsTable` or `Player` regarding a specific `Outcomes`.

The third choice seems to focus bet-handling responsibility mostly on `CrapsGame`. The game must move `Outcomes` for certain kinds of bets. Additionally, the `CrapsTable`'s `isValid` method will use the `CrapsGame` to both check the validity of individual bets as well as the entire set of bets created by a player. The first check allows or denies individual bets, something `CrapsTable` must do in collaboration with `CrapsGame`. For the second check, the `CrapsTable` assures that the total of the bets is within the table limits; something for which only the table has the information required.

**Allowed Bets.** The rule for allowed and non-allowed bets is relatively simple. When the game state has no point (also known as the come out roll), only Pass Line and Don't Pass bets are allowed, all other bets are not allowed. When the point is on, all bets are allowed. We'll have to add an `isAllowed` to `CrapsGame`, which `CrapsTable` will use when the player attempts to place a bet.

**Working Bets.** The rule for working and non-working bets is also relatively simple. On the come out roll, all odds bets placed behind any of the six Come Point numbers are not working. This rule only applies to odds behind Come Point bets; odds behind Don't Come bets are always working. We'll have to add an `isWorking` to `CrapsGame`, which `CrapsTable` will use when iterating through working bets.

The sequence of events that can lead to this condition is as follows. First, the player places a Come Line bet, the dice roll is 4, 5, 6, 8, 9 or 10, and establishes a point; the bet is moved to one of the six come points. Second, the player creates an additional odds bet placed behind this come point bet. Third, the main game point is a winner, changing the game state so the next roll is a come out roll. In this state, any additional odds behind a come point bet will be non-working bets on the come-out roll.

This kind of exceptional subtlety is one of the important reasons why object-oriented programming can be more successful than procedural programming. In this case, we can isolate this state-specific processing to the `CrapsGame`. We can also provide the interface to the `CrapsTable` that makes this responsibility explicit and easy to use.

## Design

In addition to the `CrapsTable` rework, we must also add methods to our evolving stub of the `CrapsGame` class.

### Craps Game Stub

`CrapsGame` is a preliminary design for the game of Craps. In addition to features required by the `Throw`, this version includes features required by the `CrapsTable` class.

#### Methods

- `void isAllowed(Outcome outcome);`

  Determines if the `Outcome` is allowed in the current state of the game. When the `point` is zero, it is the come out roll, and only Pass, Don't Pass, Come and Don't Come bets are allowed. Otherwise, all bets are allowed.

- `void isWorking(Outcome outcome);`

  Determines if the `Outcome` is working in the current state of the game. When the `point` is zero, it is the come out roll, odds bets placed behind any of the six come point numbers are not working.

### CrapsTable Design

`CrapsTable` is a subclass of `Table` that has an association with a `CrapsGame` object. As a `Table`, it contains all the `Bets` created by the `Player`. It also has a betting limit, and the sum of all of a player's bets must be less than or equal to this limit. We assume a single `Player` in the simulation.

#### Fields

- `CrapsGame theGame ;`

  The `CrapsGame` used to determine if a given bet is allowed or working in a particular game state.

#### Constructors

- `CrapsTable();`

  Uses the superclass for initialization of the empty `LinkedList` of bets.

#### Methods

- `void setGame(CrapsGame aGame);`

  Saves the given `CrapsGame` to be used to validate bets.

- `boolean isValid(Bet bet);`

  Validates this bet by checking with the `CrapsGame` to see if the bet is valid; it returns `true` if the bet is valid, `false` otherwise.

- `boolean allValid();`

  This uses the superclass to see if the sum of all bets is less than or equal to the table limit. If the bets are valid as a while, return `true`. Otherwise, return `false`.

## Deliverables

There are three deliverables for this exercise.

- A revision of the stub `CrapsGame` class to add methods for validating bets in different game states. In the stub, the point value of 0 means that only the “Pass Line” and “Don't Pass Line” bets are valid, where a point value of non-zero means all bets are valid.
- The `CrapsTable` subclass.
- A class which performs a unit test of the `CrapsTable` class. The unit test should create a couple instances of `Bet`, and establish that these `Bets` are managed by the table correctly.

  For testing purposes, it is easiest to have the test method simply set the the `point` variable in the `CrapsGame` instance to force a change in the game state. While public instance variables are considered by some to be a bad policy, they facilitate the creation of unit test classes.

# Chapter 29. CrapsGame Class

**Table of Contents**

In Chapter 24, *Throw Class*, we roughed out a stub version of `CrapsGame` that could be used to test `Throw`. We extended that stub in Chapter 28, *CrapsTable Class*. In this chapter, we will revise the game to provide the complete process for Craps. This involves a number of features, and we will have a state hierarchy as well as the Game class itself.

In the process of completing the design for `CrapsGame`, we will uncover another subtlety of craps: winning bets and losing bets. Unlike Roulette, where a `Bin` contained winning `Outcomes` and all other `Outcomes` where losers, Craps includes winning `Outcomes`, losing `Outcomes`, and unresolved `Outcomes`. This will lead to some rework of previously created Craps classes.

## Overview

We can see three necessary features to the `CrapsGame`: maintaining state, resolving bets and moving bets when a point is established. Also, we have some additional design features to add to other classes.

### Game State

A `CrapsGame` object cycles through the various steps of the Craps game; this sequence is shown in A Single Game of Craps. For statistical sampling purposes, we don't want to process complete games, since they have an arbitrary number of dice throws, and each throw offers additional betting opportunities. Because of all the betting opportunities, we will gather data from each individual throw of the dice. Since the dice are thrown at a predictable average rate, the length of a session depends on the number of throws and has little to do with the number of games.

Since we will follow the **State** design pattern, we have three basic design decisions. First, we have to design the state class hierarchy to own responsibilities for the unique processing of the individual states. Second, we have to design an interface for the game state objects to interact with the overall `CrapsGame`. Additionally, we will need to keep an object in the `CrapsGame` which contains the current state. Each throw of the dice will update the state, and possibly resolve game bets. To restart the game, we can create a fresh object for the initial point-off state.

The following procedure provides the detailed algorithm for the game of Craps.

**Procedure 29.1. A Single Game of Craps**

1. **Place Bets**

   The point is off; this is the come out roll. Notify the `Player` to create `Bets`. The real work of placing bets is delegated to the `Player` class. Only Pass and Don't Pass bets will be allowed by the current game state.

2. **Odds Bet Off?**

   Optional, for some casinos only. For any odds bets behind a come point, interrogate the player to see if the bet is on or off.

3. **Come-Out Roll**

   Get the next throw of the `Dice`, giving the winning `Throw`, *t*. This includes the individual `Outcomes` that can be resolved on this throw.

4. **Resolve Proposition Bets**

   For each `Bet`, *b*, placed on a one-roll proposition:

   a. **Proposition Winner?**

      If `Bet` *b*'s `Outcome` is in the winning `Throw`, *t*, then notify the `Player` that `Bet` *b* was a winner and update the `Player`'s stake. Note that the odds paid for winning field bets and horn bets depend on the `Throw`.

   b. **Proposition Loser?**

      If `Bet` *b*'s `Outcome` is not in the winning `Throw`, *t*, then notify the `Player` that `Bet` *b* was a loser. This allows the `Player` to update their betting amount for the next round.

5. **Natural?**

   If the throw is a 7 or 11, this game is an immediate winner. The game state will include the Pass Line `Outcome` as a winner.

   For each `Bet`, *b*:

   a. **Come-Out Roll Winner?**

      If `Bet` *b*'s `Outcome` is in the winning game state, then notify the `Player` that `Bet` *b* was a winner and update the `Player`'s stake. A Pass Line bet is a winner, and a Don't Pass bet is a loser.

   b. **Come-Out Roll Loser?**

      If `Bet` *b*'s `Outcome` is not in the winning game state, then notify the `Player` that `Bet` *b* was a loser. This allows the `Player` to update the betting amount for the next round. A Pass Line bet is a loser, and a Don't Pass bet is a winner.

6. **Craps?**

   If the throw is a 2, 3, or 12, this game is an immediate loser. The game state will include the Don't Pass Line `Outcome` as a winner; note that 12 is a push in this case, requiring special processing by the

`Bet` or the `Outcome`: the bet amount is simply returned.

For each `Bet`, *b*:

a. **Come-Out Roll Winner?**

   If `Bet` *b*'s `Outcome` is in the winning game state and the bet is working, then notify the `Player` that `Bet` *b* was a winner and update the `Player`'s stake. If the bet is not working, it is ignored.

b. **Come-Out Roll Loser?**

   If `Bet` *b*'s `Outcome` is not in the winning game state and the bet is working, then notify the `Player` that `Bet` *b* was a loser. If the bet is not working, it is ignored.

7. **Point Established**

   If the throw is a 4, 5, 6, 8, 9 or 10, a point is established. The game state changes, to reflect the point being on. The Pass Line and Don't Pass Line bets have a new `Outcome` assigned, based on the point.

   While the game remains unresolved, the following steps are performed. The game is resolved when the point is made or a natural is thrown.

   a. **Place Bets**

      Notify the player to place any additional bets. The game state will allow all bets.

   b. **Point Roll**

      Get the next throw of the dice.

   c. **Resolve Proposition Bets**

      Resolve any one-roll proposition bets. This is the procedure described above for iterating through all one-roll propositions. See Step 4.

   d. **Natural?**

      If the throw was 7, the game is a loser. Resolve all bets; the game state will show that all bets are active. The game state will include Don't Pass and Don't Come bets as winners, as will any of the six point bets created from Don't Pass and Don't Come Line bets. All other bets will lose, including all hardways bets. This is a extension to the basic loss resolution in Step 6.

      This throw ends the game; the point is off.

   e. **Point Made?**

      If the throw was the main game point, the game is a winner. Resolve Pass Line and Don't Pass Line bets, as well as the point and any odds behind the point. This is a extension to the basic win resolution in Step 5.

Come Point and Don't Come Point bets (and their odds) remain for the next game. A Come Line or Don't Come Line bet will be moved to the appropriate Come Point.

This throw ends the game. The point is off; odds placed behind Come Line bets are not working for the next state, the come out roll.

f. **Other Point Number?**

If the throw was any of the come point numbers, come bets on that point are winners. Resolve the point come bet and any odds behind the point. Also, any buy or lay bets will be resolved as if they were odds bets behind the point; recall that the buy and lay bets involved a commission, which was paid when the bet was created.

g. **Hardways?**

For 4, 6, 8 and 10, resolve hardways bets. If the throw was made the hard way (both dice equal), a hardways bet on the thrown number is a winner. If the throw was made the easy way, a hardways bet on the thrown number is a loser. If the throw was a 7, all hardways bets are losers. Otherwise, the hardways bets remain unresolved.

**Game State Hierarchy.** We have identified some processing that is unique to each game state. Both states will have a unique list of allowed bets, a unique list of non-working bets, a unique list of throws that cause state change and resolve game bets, and throws that resolve hardways bets.

In the Craps Table Overview, we allocated some responsibilities to `CrapsGame` for collaboration with `CrapsTable` so that the table could validate bets and determine which bets were working. Our further design details have shown that the methods in `CrapsGame` will delegate the real work to the specific state's methods. The current stub implementation checks the value of the `point` variable to determine the state. This is replaced by simply calling an appropriate method of the current state object.

Each `CrapsGameState` subclass, therefore, will have an `isValid` method that validates the state-specific bet rules. In this case, a point-off state object only allows the two Pass Line bets: Pass Line, Don't Pass Line. The point-on state allows all bets. Additionally, we've assigned to the `CrapsTable` has to determine if the total amount of all a player's bets meets or exceeds the table limits.

Each subclass of `CrapsGameState` will override the `isWorking` method with one that validates the state-specific rules for the working bets. In this case, a point-off state object will identify the the six odds bets placed behind the come point numbers (4, 5, 6, 8, 9 and 10) as non-working bets, and all other bets will be working bets. A point-on state object will simply identify all bets as working.

The subclasses of `CrapsGameState` will need methods with which to collaborate with a `Throw` object to update the state of the `CrapsGame`.

- **Point-off object.** A roll of 2, 3 or 12 resolves Pass Line and Don't Pass bets, but leaves the state unchanged. A roll of 7 or 11 resolves Pass Line and Don't Pass bets, but leaves the state unchanged. All other rolls move bets and change the state to the point-on state.

- **Point-on object.** A roll of 7 resolves all bets, and changes the state to point-off. A roll of the expected point number resolves some game and hardways bets and changes the state to point-off. All other rolls have no effect on the game state, but may resolve some hardways bets.

**Changing Game State.** We have identified two game states: point-off (also know as the come out roll) and point-on. We have also set aside four methods that the various `Throw` objects will use to change the game state. The interaction between `CrapsGame`, the four kinds of `Throws` and the two subclasses of `CrapsGameStates` works as follows:

1. The `Game` object calls the `Throw`'s `updateGame` method. This method has different implementations for each of the subclasses of `Throw`. There are 36 instances of `Throw`, one of which is selected at random to be the current throw of the dice.

2. The `Throw` object calls one of the `Game`'s methods to change the state. There are four methods available: `craps`, `natural`, `eleven`, and `point`. Each subclass of `Throw` will call an appropriate method for the kind of throw.

3. The `Game` will delegate each of the four state change methods (`craps`, `natural`, `eleven`, and `point`) to the current `CrapsGameState` object. There are two subclasses, depending on the state of the point: point-on and point-off.

4. In parallel with `Game`, each `CrapsGameState` object has four state change methods (`craps`, `natural`, `eleven`, and `point`). Each state provides different implementations for these methods. In effect, the two states and four methods create a kind of table that enumerates all possible state change rules.

At first glance the indirection and delegation seems like a lot of overhead for a simple state change. When we consider the kinds of decision-making this embodies, however, we can see that this is an effective solution. When one of the 36 available `Throws` has been chosen, the `CrapsGame` calls a single method to update the game state. Because the various subclasses of `Throw` are polymorphic, they all respond with unique, correct behavior. Similarly, each of the subclasses of `Throw` simply uses one of four methods to update the `CrapsGame`, without having to discern the current state of the `CrapsGame`. We can consider `CrapsGame` as a kind of façade over the methods of the polymorphic `CrapsGameState`. Our objective is to do the decision-making once when the object is created; this makes all subsequent processing free of complex decision-making (i.e., simple) but indirect.

## Bet Resolution

The `CrapsGame` class also has the responsibility for matching the `Outcomes` in the current `Throw` with the `Outcomes` of the `Bets` on the `CrapsTable`. In addition to matching `Outcomes` in the `Throw`, we also have to match the `Outcomes` of the current game state, and resolve hardways bets, which are casually tied to the current game state. We'll look at each of these three resolution procedures in some detail before making a final decision.

**Resolving Bets on Proposition Outcomes.** The first bet resolution method handles one-roll propositions. This is similar to the bet resolution in the Roulette game class. The current `Throw` contains a collection of `Outcomes` which are resolved as winners. All other `Outcomes` were losers. While appropriate for the one-roll propositions, we'll see that this doesn't work well for other kinds of bets.

**Resolving Bets on Game Outcomes.** The second, and most complex bet resolution method handles game outcomes. Bets on the game as a whole have three groups of `Outcomes`: winners, losers and unresolved. Consider a Pass Line bet: in the point-off state, a roll of 7 or 11 makes this bet a winner, a roll of 2, 3 or 12 makes this bet a loser, all other numbers leave this bet unresolved. After a point is established, this Pass Line bet has the following resolutions: a roll of 7 makes this bet a loser, rolling the point makes this bet is a wiunner, all other numbers leave this bet unresolved.

In addition to this three-way decision, we have the additional subtlety of Don't Pass Line bets that can lead to a fourth resolution: a push when the throw is 12 on a come out roll. We don't want to ignore this detail because it changes the odds by almost 3%.

We have three choices for implementations of this multi-way decision.

- We can keep separate collections of winning and losing `Outcomes` in each `Throw`. This will obligate the game to check a set winners and a set of losers for bet resolution.
- We can add a method to the `Bet` class that will return a code for the various effects of win, lose or wait for each `Outcome`. This means that the game will have to decode the response as part of bet resolution.
- We can make each effect a method of `Player`, and have each `Outcome` call an appropriate method. The `Outcome` will need to collaborate with the game state in order to determine whether to call the winner or loser methods.

**Winning and Losing Collections.** If we elect to keep separate collections of winners and losers, we must detail both the winning and losing `Outcomes` for each state. All other `Outcomes` would be left unresolved. This is a minor revision to `Dice` and `Throw` to properly create the more sophisticated `Outcomes`. Consequently `ThrowBuilder` will have to be expanded to identify losing `Outcomes` in addition to the existing winning `Outcomes`.

In this case, the `CrapsGame` must match all active `Bets` on the `CrapsTable` against the winning `Outcomes` in the current `CrapsGameState`; the matches are paid a winning amount and removed. It would also match match all active `Bets` on the `CrapsTable` against the losing `Outcomes` in the current `CrapsGameState`; these are removed as losers.

**Winning and Losing Codes, Evaluated by CrapsGame.** Instead of using simple membership in a set of winning `Outcomes`, we could implement a three-way discrimination between won, lost, and unresolved. In this case, we have to define the three result codes and provide a method that determines the appropriate code value. Along with simple integer codes, we use a `switch` statement in a method of `CrapsGame` to implement the various effects.

In this option, the `CrapsGame` must match all active `Bets` on the `CrapsTable` against `Outcomes` in the current `CrapsGameState`, the matching method would return a code for winning, losing or waiting. When the `Bet` matching resulted in the code for winning, this is paid a winning amount and removed. When the `Bet` matching resulted in the code for losing, this is removed.

Also note that if we elect to introduce a three-way discrimination, we have to decide if we should reimplement the bet resolution in Roulette. Using very different bet resolution algorithms for Craps and Roulette would increase the cost of maintenance and adaptation. While a uniform approach is beneficial, it would involve some rework of the Roulette game to make use of this more sophisticated design.

**Winning and Losing Methods of Player.** Instead of using integer result codes, and a `switch` statement to implement the various effects, we can more directly empower the `Bet` to call win or lose methods of the `Player`. By using methods directly, we no longer have to maintain a set of potentially obscure numeric codes and translate from a numeric code to a method invocation.

The `CrapsGame` class must iterate through all active `Bets` on the `CrapsTable`, giving the `Bet` to the current `CrapsGameState` for resolution. If the `Bet` matched a winning `Outcomes` in the current `CrapsGameState`, the player is paid a winning amount and the bet is removed. When the `Bet` matched a losing outcome, the bet is removed.

Before making a determination, we'll examine the remaining bet resolution issue to see if a single approach can cover single-roll, game and hardways outcomes.

**Resolving Bets on Hardways Outcomes.** In addition to methods to resolve one roll and game bets, we have to resolve the hardways bets. Hardways bets are similar to game bets. For `Throws` of 4, 6, 8 or 10 there will be one of three outcomes: when the number is made the hard way, the matching hardways bet is a winner; when the number is made the easy way, the matching hardways bet is a loser; otherwise the hardways bet is unresolved. On a roll of seven, all hardways bets are losers.

Since this parallels the game rules, but applies to a `Throw`, it leads us to consider the design of `Throw` to be parallel to the design of `CrapsGame`. We can use either a collection of losing `Outcomes` in addition to the collection of winning `Outcomes`, or create a multi-way discrimination method, or have the `Throw` call appropriate methods of `CrapsTable` to resolve the bet.

**Conclusion.** A resonably flexible design for `Bet` resolution that works for all three kinds of bet resolutions is to have `Throw` and `CrapsGameState` call specific bet resolution methods in `CrapsPlayer`. This unifies one-roll, game and hardways bets into a single mechanism. It requires us to provide methods for win, lost and push in the `CrapsPlayer`. We can slightly simplify this to treat a push as a kind of win that returns the bet amount.

The `CrapsGame` will provide the active `Bets` to the current `Throw` for resolving one-roll and hardways bets. Each `Bet` will also be examined by the `CrapsGameState` to resolve the winning and losing game bets. The implementation is simplified if each `Bet` carries a reference to the owning `Player`. In this way, the `Bet` has all the information necessary to notify the `Player`.

Our bet resolution method in the game can accept an `Iterator` over all `Bets` on the `CrapsTable`. After determining the state transition condition, the state can then iterate through the bets, resolving any winners and losers. A similar approach can be used by the `Throw` to resolve one-roll and hardways bets.

## Moving Bets

In the casino, the Come (and Don't Come) Line bets start on the given line. If a come point is established, the line bet is moved to a numbered box. When you add behind the line odds bets, you place the chips directly on the on the numbered box for the come point number. This is different from the Pass (and Don't Pass) Line bet. The bet is is placed on the line. If a point is established, a large white token shows the numbered box where, in effect, the behind the line odds chips belong.

One of the things the `CrapsGame` does is change the `Outcome` of the Come and Don't Come Line bets. These

`Outcomes` are bets that may be resolved in one roll, or they are moved to one of the six point number `Outcomes` (4, 5, 6, 8, 9, and 10) if they are not resolved. The bet is changed to an `Outcome` based on the number thrown. When designing the `Bet` class, in the Craps Bet Overview, we recognized the need to change the `Outcome` from a generic “Pass Line Odds” to a specific point with specific odds of 2:1, 3:2 or 6:5.

The Pass Line Odds and Don't Pass Odds are placed after the point is established. Since the point is already known, creating these bets is best done by adding a `pointOutcome` method to `CrapsGame` that returns an `Outcome` based on the current point. This allows the `CrapsPlayer` to get the necessary `Outcome` object, create a `Bet` and give that `Bet` to the `CrapsTable`.

We'll develop a `moveToThrow` method that accepts a `Bet` and the current `Throw` and move that bet to an appropriate new `Outcome`.

## Additional Craps Design

We will have to rework our design for `Throw` to have both a one-roll resolution method and a hardways resolution method. Each of these methods will accept a single active `Bet`. The one-roll resolution method could use a Set of winner `Outcomes` and a Set of loser `Outcomes` to attempt to resolve the `Bet`. Similarly, the hardways resolution method could use two sets of `Outcomes`.

We will also need to rework our design for `Dice` to correctly set both winners and losers for both one-roll and harways bets when constructing the 36 individual `Throw` instances.

We can use the following expanded algorithm for building the `Dice`. This is a revision to Building Dice to include lists of losing bets as well as winning bets.

**Procedure 29.2. Building Dice With Winning and Losing Outcomes**

- **For All Faces Of Die 1.** For $d_1$ in the range 1 to 6

    a. **For All Faces Of Die 2.** For $d_2$ in the range 1 to 6

        i. **Sum the Dice.** Compute the sum, $s$, as $d_1+d_2$.

        ii. **Craps?** If $s$ is in 2, 3, and 12, we create a `CrapsThrow` instance. This will include one of the 2, 3 or 12 number `Outcome`, plus any craps, horn and field `Outcomes`. The other number `Outcome` are all losers. This throw does not resolve hardways bets.

        iii. **Point?** For $s$ in 4, 5, 6, 8, 9, and 10 we will create a `PointThrow` instance.

            A. **Hard way?** When $d_1 = d_2$, this is a *hard* 4, 6, 8 or 10. The appropriate hard number `Outcome` is a winner.

            B. **Easy way?** Otherwise, this is an *easy* 4, 6, 8 or 10. The appropriate hard number `Outcome` is a loser.

            C. **Field?** For $s$ in 4, 9 and 10 we include the field `Outcome` as a winner. Otherwise the field `Outcome` is a loser.

D. **Losing Propositions.** Other one-roll `Outcomes`, including 2, 3, 7, 11, 12, Horn and Any Craps are all losers for this `Throw`.

iv. **Natural?** If *s* is 7, we create a `NaturalThrow` instance. This will also include a 7 `Outcome` as a winner. It will have numbers 2, 3, 11, 12, horn, field and any craps are all losers for this `Throw`. Also, all four hardways are losers for this throw.

v. **Eleven?** If *s* is 11, we create an `ElevenThrow` instance. This will include 11, horn and field `Outcomes` as winners. It will have numbers 2, 3, 7, 12 and any craps as losers for this `Throw`. There is no hardways resolution.

**Craps Player Class Hierarchy.** Still to be designed is the actual `CrapsPlayer`. This is really a complete tree of classes, each of which provides a different betting strategy. We will defer this design work until later. For the purposes of making the `CrapsGame` work, we can develop our unit tests with a kind of stub for `CrapsPlayer` which simply places a single Pass Line `Bet`. In several future exercises, we'll revisit this design to make more sophisticated players.

See Optional Working Bets for a further discussion on an additional player decision offered by some variant games. Our design can be expanded to cover this. We'll leave this as an exercise for the more advanced student. This involves a level of collaboration between `CrapsPlayer` and `CrapsGame` that is over the top for this part. We'll address this kind of very rich interaction in Part III, "Blackjack".

### Optional Working Bets

Some casinos may give the player an option to declare the odds bet behind a come point as "on" or "off". This is not particularly complex to implement. There are a number of simple changes required if we want to add this interaction between `CrapsPlayer` and `CrapsGame`. First, we must add a method to the `CrapsPlayer` to respond to a query from the `CrapsGame` that determines if the player wants their come point odds bet on or off. Second, we need to update `Bet` to store the `Player` who created the `Bet`. Third, the `CrapsGame` gets the relevant `Bets` from the `Table`, and interrogates the `Player` for the disposition of the `Bet`.

## Design

Changing the `Throw` to include both winning and losing `Outcomes` is an important change. Once we have fixed the `Throw` class, we can update the `ThrowBuilder` class to do a correct initialization using both winners and losers. Note that we have encapsulated this information so that there is no change to `Dice`.

We will also update `Bet` to carry a reference to the `Player` to make it easier to post winning and losing information directly to the player object.

We will need to create a stub `CrapsPlayer` for testing purposes.

We will also need to create our `CrapsGameState` class hierarchy to represent the two states of the game.

Once the preliminary work is complete, we can then transform our `CrapsStub` into the a final version of `CrapsGame`. It will collaborate with a `CrapsPlayer` and maintain a correct `CrapsGameState`. It will be able to get a random `Throw` and resolve `Bet`s.

## Throw Rework

`Throw` is the superclass for the various throws of the dice. A `Throw` identifies two sets of `Outcomes`: immediate winners and immediate losers. Each subclass is a different grouping of the numbers, based on the state-change rules for Craps.

### Fields

- `Set win1Roll ;`

  A collection of one-roll `Outcomes` that win with this throw.

- `Set lose1Roll ;`

  A collection of one-roll `Outcomes` that lose with this throw.

- `Set winHardway ;`

  A collection of hardways `Outcomes` that win with this throw. Not all throws resolve hardways bets, so this and the loseHardway Set may both be empty.

- `Set loseHardway ;`

  A collection of hardways `Outcomes` that lose with this throw. Not all throws resolve hardways bets, so this and the winHardway Set may both be empty.

- `int d1 ;`

  One of the two die values, from 1 to 6.

- `int d2 ;`

  The other of the two die values, from 1 to 6.

### Constructors

-
  ```
  Throw(int d1,
        int d2);
  ```

  Creates this throw. `Outcomes` can be added later.

-
  ```
  Throw(int d1,
        int d2,
        Set winners,
  ```

```
      Set losers);
```

Creates this throw, and associates the two given `Sets` of `Outcomes` that are winning one-roll propositions and losing one roll propositions.

-
  ```
  Throw(int d1,
        int d2,
        Outcome[] winners,
        Outcome[] losers);
  ```

  Creates this throw, and creates the `Sets` of winning and losing one-roll proposition `Outcomes` from the given arrays of `Outcomes`.

## Methods

-
  ```
  void add1Roll(Outcome[] winners,
                Outcome[] losers);
  ```

  Adds outcomes to the one-roll winners and one-roll losers Sets.

-
  ```
  void addHardways(Outcome[] winners,
                   Outcome[] losers);
  ```

  Adds outcomes to the hardways winners and hardways losers Sets.

- `boolean hard();`

  Returns `true` if `d1` is equal to `d2`. This helps determine if hardways bets have been won or lost.

- `abstract void updateGame(Game theGame);`

  Calls one of the `Game` state change methods: `craps`, `natural`, `eleven`, `point`. This may change the game state and resolve bets.

- `abstract boolean resolveOneRoll(Bet aBet);`

  If this `Bet`'s `Outcome` is in the Set of one-roll winners, pay the `Player` that created the `Bet`. Return `true` so that this `Bet` is removed.

  If this `Bet`'s `Outcome` is in the Set of one-roll losers, return `true` so that this `Bet` is removed.

  Otherwise, return `false` to leave this `Bet` on the table.

- `abstract boolean resolveHardways(Bet aBet);`

  If this `Bet`'s `Outcome` is in the Set of hardways winners, pay the `Player` that created the `Bet`. Return `true` so that this `Bet` is removed.

  If this `Bet`'s `Outcome` is in the Set of hardways losers, return `true` so that this `Bet` is removed.

Otherwise, return `false` to leave this `Bet` on the table.

- An easy-to-read String output method is also very handy. This should return a String representation of the dice. A form that looks like `1,2` works nicely.

## ThrowBuilder Rework

`ThrowBuilder` initializes the 36 `Throws`, each initialized with the appropriate `Outcomes`. Subclasses can override this to reflect different casino-specific rules for odds on Field bets.

### Methods

- `buildThrows(Dice theDice);`

  Creates the 8 one-roll `Outcome` instances (2, 3, 7, 11, 12, Field, Horn, Any Craps), as well as the 8 hardways `Outcome` instances (easy 4, hard 4, easy 6, hard 6, easy 8, hard 8, easy 10, hard 10). It then creates each of the 36 `Throws`, each of which has the appropriate combination of `Outcomes` for one-roll and hardways. The `Throws` are assigned to *`theDice`*.

## Bet Rework

`Bet` associates an amount, an `Outcome` and a `Player`. The `Game` may move a `Bet` to a different `Outcome` to reflect a change in the odds used to resolve the `Bet`.

### Constructors

-
  ```
  Bet(int amount,
      Outcome outcome,
      Player player);
  ```

  Initialize the instance variables of this bet.

## CrapsPlayer Class Stub

`CrapsPlayer` constructs a `Bet` based on the `Outcome` named `"Pass Line"`. This is a very persistent player.

### Fields

- `Outcome passLine = null;`

  This is the outcome on which this player focuses their betting. It will be an instance of the `"Pass Line" Outcome`, with 1:1 odds.

- `Bet workingBet = null;`

  This is the current Pass Line `Bet`. Initially this is `null`. Each time the bet is resolved, this is reset to `null`. This assures that only one bet is working at a time.

- `Table table ;`

  Used to place individual bets.

### Constructors

- `CrapsPlayer(Table aTable);`

  Constructs the `CrapsPlayer` with a specific table for placing bets. The player creates a single `"Pass Line" Outcome`, which is saved in the `passLine` variable for use in creating `Bets`.

### Methods

- `void placeBets();`

  If `workingBet` is `null`, create a new Pass Line `Bet`, and uses `Table placeBet` to place that bet.

  If `workingBet` is not `null`, the bet is still working. Do not place any more bets.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The amount of money won is available via `theBet winAmount`.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser.

## CrapsGameState Class

`CrapsGameState` defines the state-specific behavior of a Craps game. Individual subclasses provide methods used by `CrapsTable` to validate bets and determine the active bets. Subclasses provide state-specific methods used by a `Throw` to possibly change the state and resolve bets.

### Fields

- `CrapsGame theGame = null;`

  The overall `CrapsGame`. From this, the various next state methods can get the `CrapsTable` and an `Iterator` over the active `Bets`.

### Constructors

- `CrapsGameState(CrapsGame theGame);`

Saves the overall `CrapsGame` object.

### Methods

- `abstract boolean isValid(Outcome anOutcome);`

  Each subclass provides a unique definition of valid bets for their game state.

- `abstract boolean isWorking(Outcome anOutcome);`

  Each subclass provides a unique definition of active bets for their game state.

- `abstract CrapsGameState craps();`

  Each subclass returns an appropriate state when a 2, 3 or 12 is rolled. It then resolves any game bets.

- `abstract CrapsGameState natural();`

  Each subclass returns an appropriate state when a 7 is rolled. It then resolves any game bets.

- `abstract CrapsGameState eleven();`

  Each subclass returns an appropriate state when an 11 is rolled. It then resolves any game bets.

- `abstract CrapsGameState point(Throw throw);`

  Each subclass returns an appropriate state when the given point number is rolled. It then resolves any game bets.

- `abstract Outcome pointOutcome();`

  Returns the `Outcome` based on the current point. This is used to create Pass Line Odds or Don't Pass Odds bets. This delegates the real work to the current `CrapsGameState` object.

-
  ```
  void moveToThrow(Bet aBet,
                   Throw theThrow);
  ```

  Moves a Come Line or Don't Come Line bet to a new `Outcome` based on the current throw. If the value of `theThrow` is 4, 5, 6, 8, 9 or 10, this delegates the move to the current `CrapsGameState` object. For values of 4 and 10, the odds are 2:1. For values of 5 and 9, the odds are 3:2. For values of 6 and 8, the odds are 6:5. For other values of `theThrow`, this method does nothing.

- `public String toString();`

  In the superclass, this doesn't do anything. Each subclass, however, should display something useful.

## CrapsGamePointOff Class

`CrapsGamePointOff` defines the behavior of the Craps game when the point is off. It defines the allowed bets and the active bets. It provides methods used by a `Throw` to change the state and resolve bets.

All four of the game update methods (craps, natural, eleven and point) use the same basic algorithm. The method will get the `CrapsTable` from `theGame`. From the `CrapsTable`, the method gets the `Iterator` over the `Bets`. It can then match each `Bet` against the various `Outcomes` which win and lose, and resolve the bets.

### Fields

- Currently, none.

### Constructors

- `CrapsGamePointOff(CrapsGame theGame);`

  Saves the overall `CrapsGame` object.

### Methods

- `abstract boolean isValid(Outcome anOutcome);`

  There are two valid `Outcomes`: Pass Line, Don't Pass Line. All other `Outcomes` are invalid.

- `abstract boolean isWorking(Outcome anOutcome);`

  There are six non-working `Outcomes`: “Come Odds 4”, “Come Odds 5”, “Come Odds 6”, “Come Odds 8”, “Come Odds 9” and “Come Odds 10”. All other `Outcomes` are working.

- `CrapsGameState craps();`

  When the point is off, a roll of 2, 3 or 12 means the game is an immediate loser. The Pass Line `Outcome` is a loset. If the `Throw` value is 12, a Don't Pass Line `Outcome` is a push, otherwise the Don't Pass Line `Outcome` is a winner. The next state is the same as this state, and the method should return `this`.

- `abstract CrapsGameState natural();`

  When the point is off, 7 means the game is an immediate winner. The Pass Line `Outcome` is a winner, the Don't Pass Line `Outcome` is a loser. The next state is the same as this state, and the method should return `this`.

- `abstract CrapsGameState eleven();`

  When the point is off, 11 means the game is an immediate winner. The Pass Line `Outcome` is a winner, the Don't Pass Line `Outcome` is a loser. The next state is the same as this state, and the method should return `this`.

- `abstract CrapsGameState point(Throw throw);`

When the point is off, a new point is established. This method should return a new instance of `CrapsGamePointOn` created with the given `Throw`'s value. Note that any Come Point bets or Don't Come Point bets that may be on this point are pushed to player: they can't be legal bets in the next game state.

- `abstract Outcome pointOutcome();`

  Returns the `Outcome` based on the current point. This is used to create Pass Line Odds or Don't Pass Odds bets. This delegates the real work to the current `CrapsGameState` object. Since no point has been established, this returns `null`.

- `public String toString();`

  The point-off state should simply report that the point is off, or that this is the come out roll.

## CrapsGamePointOn Class

`CrapsGamePointOn` defines the behavior of the Craps game when the point is on. It defines the allowed bets and the active bets. It provides methods used by a `Throw` to change the state and resolve bets.

### Fields

- `int point ;`

  The point value.

### Constructors

-
  ```
  CrapsGamePointOn(CrapsGame theGame,
                   int thePoint);
  ```

  Saves the overall `CrapsGame` object. Saves the given point value.

### Methods

- `abstract boolean isValid(Outcome anOutcome);`

  It is invalid to Buy or Lay the `Outcomes` that match the point. If the point is 6, for example, it is invalid to buy the “Come Point 6” `Outcome`. All other `Outcomes` are valid.

- `abstract boolean isWorking(Outcome anOutcome);`

  All `Outcomes` are working.

- `CrapsGameState craps();`

  When the point is on, 2, 3 and 12 do not change the game state. The Come Line `Outcome` is a loser, the Don't Come Line `Outcome` is a winner. The next state is the same as this state, and the method should return `this`.

- `abstract CrapsGameState natural();`

  When the point is on, 7 means the game is a loss. Pass Line `Outcomes` lose, as do the pass-line odds `Outcomes` based on the point. Don't Pass Line `Outcomes` win, as do all Don't Pass odds `Outcome` based on the point. The Come Line `Outcome` is a winner, the Don't Come Line `Outcome` is a loser. However, all Come Point number `Outcomes` and Come Point Number odds `Outcome` are all losers. All Don't Come Point number `Outcomes` and Don't Come Point odds `Outcomes` are all winners. The next state is a new instance of the `CrapsGamePointOff` state.

  Also note that the `Throw` of 7 also resolved all hardways bets. A consequence of this is that all `Bets` on the `CrapsTable` are resolved.

- `abstract CrapsGameState eleven();`

  When the point is on, 11 does not change the game state. The Come Line `Outcome` is a winner, and the Don't Come Line `Outcome` is a loser. The next state is the same as this state, and the method should return `this`.

- `abstract CrapsGameState point(Throw throw);`

  When the point is on and the value of `throw` doesn't match `point`, then the various Come Line bets can be resolved. Come Point `Outcomes` for this number (and their odds) are winners. Don't Come Line `Outcomes` for this number (and their odds) are losers. Other Come Point number and Don't Come Point numbers remain, unresolved. Any Come Line bets are moved to the Come Point number `Outcomes`. For example, a throw of 6 moves the `Outcome` of the Come Line `Bet` to Come Point 6. Don't Come Line bets are moved to be Don't Come number `Outcomes`. The method should return `this`.

  When the point is on and the value of `throw` matches `point`, the game is a winner. Pass Line `Outcomes` are all winners, as are the behind the line odds `Outcomes`. Don't Pass line `Outcomes` are all losers, as are the Don't Pass Odds `Outcomes`. Come Line bets are moved to thee Come Point number `Outcomes`. Don't Come Line bets are moved to be Don't Come number `Outcomes`. The next state is a new instance of the `CrapsGamePointOff` state.

- `abstract Outcome pointOutcome();`

  Returns the `Outcome` based on the current point. This is used to create Pass Line Odds or Don't Pass Odds bets. This delegates the real work to the current `CrapsGameState` object. For points of 4 and 10, the `Outcome` odds are 2:1. For points of 5 and 9, the odds are 3:2. For points of 6 and 8, the odds are 6:5.

- `public String toString();`

  The point-off state should simply report that the point is off, or that this is the come out roll.

## CrapsGame Class

`CrapsGame` manages the sequence of actions that defines the game of Craps. This includes notifying the `Player` to place bets, throwing the `Dice` and resolving the `Bets` actually present on the `Table`.

Note that a single cycle of play is one throw of the dice, not a complete craps game. The state of the game may or may not change.

### Fields

- `Dice theDice ;`

  Contains the dice that returns a randomly selected `Throw` with winning and losing `Outcomes`.

- `CrapsTable theTable ;`

  Contains the bets placed by the player.

- `CrapsPlayer thePlayer ;`

  Places bets on the table.

### Constructors

- We based this constructor on an design that allows any of these objects to be replaced. This is the **Strategy** design pattern. Each of these objects is a replaceable strategy, and can be changed by the client that uses this game.

  Additionally, we specifically do not include the `Player` instance in the constructor. The `Game` exists independently of any particular `Player`, and we defer binding the `Player` and `Game` until we are gathering statistical samples.

  ```
  CrapsGame(Dice someDice,
            CrapsTable aTable);
  ```

  Constructs a new `CrapsGame`, using a given `Dice` and `CrapsTable`.

### Methods

- `void cycle(Player aPlayer);`

  This will execute a single cycle of play with a given `Player`.

  1. It will call `thePlayer` `placeBets` to get bets. It will validate the bets, both individually, based on the game state, and collectively to see that the table limits are met.

  2. It will call `theDice` `next` to get the next winning `Throw`.

3. It will use the `Throw`'s `updateGame` to advance the game state.
4. It will then call `theTable bets` to get an `Iterator`; stepping through this `Iterator` returns the individual `Bet` objects.
    - It will use the `Throw`'s `resolveOneRoll` method to check one-roll propositions. If the method returns true, the `Bet` is resolved and should be deleted.
    - It will use the `Throw`'s `resolveHardways` method to check the hardways bets. If the method returns true, the `Bet` is resolved and should be deleted.

- `Outcome pointOutcome();`

  Returns the `Outcome` based on the current point. This is used to create Pass Line Odds or Don't Pass Odds bets. This delegates the real work to the current `CrapsGameState` object.

-
  ```
  void moveToThrow(Bet aBet,
                   Throw theThrow);
  ```

  Moves a Come Line or Don't Come Line bet to a new `Outcome` based on the current throw. If the value of `theThrow` is 4, 5, 6, 8, 9 or 10, this delegates the move to the current `CrapsGameState` object. For other values of `theThrow`, this method does nothing.

- `void reset();`

  This will reset the game by setting the state to a new instance of `GamePointOff`. It will also tell the table to clear all bets.

## Deliverables

There are over a dozen deliverables for this exercise. This includes significant rework for `Throw` and `Dice`. It also includes development of a stub `CrapsPlayer`, the `CrapsGameState` hierarchy and the first version of the `CrapsGame`. We will break the deliverables down into two groups.

**Rework.** The first group of deliverables includes the rework for `Throw` and `Dice`, and all of the associated unit testing.

- The revised and expanded `Throw` class. This will ripple through the constructors for all four subclasses, `NaturalThrow`, `CrapsThrow`, `ElevenThrow`, `PointThrow`.
- Five updated unit tests for the classes in the `Throw` class hierarchy. This will confirm the new functionality for holding winning as well as losing `Outcome`s.
- The revised and expanded `ThrowBuilder`. This will construct `Throw`s with winning as well as losing `Outcome`s.
- A unit test for the `Dice` class that confirms the new initializer that creates winning as well as losing `Outcome`s.

**New Development.** The second group of deliverables includes development of a stub `CrapsPlayer`, the `CrapsGameState` hierarchy and the first version of the `CrapsGame`. This also includes significant unit testing.

- The `CrapsPlayer` class atub. We will rework this design later. This class places a bet on the Pass Line when there is no Pass Line `Bet` on the table. One consequence of this is that the player will be given some opportunities to place bets, but will decline. Since this is simply used to test `CrapsGame`, it doesn't deserve a very sophisticated unit test of its own. It will be replaced in a future exercise.
- A revised `Bet`, which carries a reference to the `Player` who created the `Bet`. This will ripple through all subclasses of `Player`, forcing them to all add the `this` parameter when constructing a new `Bet`.
- The `CrapsGame` class.
- A class which performs a demonstration of the `CrapsGame` class. This demo program creates the `Dice`, the stub `CrapsPlayer` and the `CrapsTable`. It creates the `CrapsGame` object and cycles a few times. Note that we will need to configure the `Dice` to return non-random results.

We could, with some care, refactor our design to create some common superclasses between Roulette and Craps to extract features of `Throw` so they can be shared by `Throw` and `Bin`. Similarly, there may be more common features between `RouletteGame` and `CrapsGame`. We'll leave that as an exercise for more advanced students.

# Chapter 30. CrapsPlayer Class

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The variations on `Player`, all of which reflect different betting strategies, is the heart of this application. In Chapter 10, *Roulette Game Class*, we roughed out a stub class for `Player`, and refined it in Chapter 12, *Player Class*. We will further refine this definition of `Player` for use in Craps.

## Overview

We have now built enough infrastructure that we can begin to add a variety of players and see how their betting strategies work. Each player is betting algorithm that we will evaluate by looking at the player's stake to see how much they win, and when they stop playing because they've run out of time or gone broke.

The `Player` has the responsibility to create bets and manage the amount of their stake. To create bets, the player must create legal bets from known `Outcomes` and stay within table limits. To manage their stake, the player must deduct the price of a bet when it is created, accept winnings or pushes, report on the current value of the stake, and leave the table when they are out of money.

We have an interface that was roughed out as part of the design of `CrapsGame` and `CrapsTable`. In designing `CrapsGame`, we put a `placeBets` method in `CrapsPlayer` to place all bets. We expected the `CrapsPlayer` to create `Bets` and use the `placeBet` method of `CrapsTable` class to save all of the individual `Bets`.

In an earlier exercise, we built a stub version of `CrapsPlayer` in order to test `Game`. See CrapsPlayer Class Stub. When we finish creating the final superclass, `CrapsPlayer`, we will also revise our `CrapsPlayerStub` to be more complete, and rerun our unit tests to be sure that our more expanded design still handles the basic test cases correctly.

Our objective is to have a new abstract class, `CrapsPlayer`, with a concrete subclass that follows the Martingale system, using simple Pass Line bets and behind the line odds bets.

We'll defer some of the design required to collect detailed measurements for statistical analysis. In this first release, we'll simply place bets. Most of the `Simulator` class that we built for Roulette should be applicable to Craps without significant modification.

Our basic `CrapsPlayer` will place a Pass Line bet and a Pass Line Odds bet. This requires the player to interact with the `CrapsTable` or the `CrapsGame` to place bets legally. On a come out roll, only the Pass Line will be legal. After that, a single Pass Line Odds bet can be placed. This leads to three betting rules:

- Come Out Roll. Condition: No Pass Line Bet is currently placed and only the Pass Line bet is legal. Action: Place a Pass Line bet.
- First Point Roll. Condition: No odds bets is currently placed and odds bets are legal. Action: Place a Pass Line Odds bet.
- Other Point Roll. Condition: An odds bets is currently placed. Action: Do Nothing.

Beyond simply placing Pass Line and Pass Line Odds bets, we can use a Martingale or a Cancellation betting system to increase our bet on each loss, and decrease our betting amount on a win. Since we have two different bets in play -- a single bet created on the come out roll, a second odds bet if possible -- the simple Martingale system doesn't work well. In some casinos, the behind the line odds bet can be double the pass line bet, or even 10 times the pass line bet, giving us some complex betting strategies. For example, we could apply the Martingale system only to the odds bet, leaving the pass line bet at the table minimum. We'll set this complexity aside for the moment, build a simple player first.

## Design

### CrapsPlayer Superclass

`CrapsPlayer` is a subclass of `Player` and places bets in Craps. This an abstract class, with no actual body for the `placeBets` method. However, this class does implement the basic `win` and `lose` methods used by all subclasses.

Since this is a subclass of the basic Roulette player, we inherit several useful features. Most of the features of `Player` are repeated here for reference purposes only.

### Fields

- `int stake ;`

  The player's current stake. Initialized to the player's starting budget.

- `int roundsToGo ;`

  The number of rounds left to play. Initialized by the overall simulation control to the maximum number of rounds to play. In Roulette, this is spins. In Craps, this is the number of throws of the dice, which may be a large number of quick games or a small number of long-running games. In Craps, this is the number of cards played, which may be large number of hands or small number of multi-card hands.

- `CrapsTable table ;`

  Used to place individual `Bet`s.

### Constructors

- `Player(CrapsTable aTable);`

  Constructs the `Player` with a specific `CrapsTable` for placing `Bet`s.

### Methods

- `boolean playing();`

  Returns `true` while the player is still active. A player with a stake of zero will be inactive. Because of the indefinite duration of a craps game, a player will only become inactive after their `roundsToGo` is zero and they have no more active bets. This method, then, must check the `CrapsTable` to see when all the bets are fully resolved. Additionally, the player's betting rules should stop placing new bets when the `roundsToGo` is zero.

- `void placeBets();`

  Updates the `CrapsTable` with the various `Bet`s.

  When designing the `CrapsTable`, we decided that we needed to deduct the price of the bet from the stake when the bet is created. See the Roulette Table Overview for more information on the timing of this deduction, and the Craps Bet Overview for more information on the price of a bet.

- `void win(Bet theBet);`

  Notification from the `CrapsGame` that the `Bet` was a winner. The amount of money won is available via `theBet` `winAmount`.

- `void lose(Bet theBet);`

  Notification from the `CrapsGame` that the `Bet` was a loser.

## CrapsPlayerPass Subclass

`CrapsPlayerPass` is a `CrapsPlayer` who places a Pass Line bet in Craps.

### Methods

- `void placeBets();`

  If no Pass Line bet is present, this will update the `Table` with a bet on the Pass Line at the base bet amount.

  Otherwise, this method does not place an additional bet.

## Craps Martingale Subclass

`CrapsMartingale` is a `CrapsPlayer` who places bets in Craps. This player doubles their Pass Line Odds bet on every loss and resets their Pass Line Odds bet to a base amount on each win.

### Fields

- `int lossCount ;`

  The number of losses. This is the number of times to double the pass line odds bet.

- `int betMultiple ;`

  The the bet multiplier, based on the number of losses. This starts at 1, and is reset to 1 on each win. It is doubled in each loss. This is always equal to $2^{lossCount}$.

### Methods

- `void placeBets();`

  If no Pass Line bet is present, this will update the `Table` with a bet on the Pass Line at the base bet amount.

  If no Pass Line Odds bet is present, this will update the `Table` with an Pass Line Odds bet. The amount is the base amount times the `betMultiple`.

Otherwise, this method does not place an additional bet.

- `void win(Bet theBet);`

  Uses the superclass `win` method to update the stake with an amount won. This method then resets `lossCount` to zero, and resets `betMultiple` to `1`.

- `void lose(Bet theBet);`

  Increments `lossCount` by `1` and doubles `betMultiple`.

## Deliverables

There are six deliverables for this exercise.

- The `CrapsPlayer` abstract superclass. Since this class doesn't have a body for the `placeBets` method, it can't be unit tested directly.
- A `CrapsPlayerPass` class that is a proper subclass of `CrapsPlayer`, but simply places bets on Pass Line until the stake is exhausted.
- A unit test class for `CrapsPlayerPass`. This test should synthesize a fixed list of `Outcomes`, `Throws`, and calls a `CrapsPlayerPass` instance with various sequences of craps, naturals and points to assure that the pass line bet is made appropriately.
- The `CrapsMartingale` subclass of `CrapsPlayer`.
- A unit test class for `CrapsMartingale`. This test should synthesize a fixed list of `Outcomes`, `Throws`, and calls a `CrapsMartingale` instance with various sequences of craps, naturals and points to assure that the bet doubles appropriately on each loss, and is reset on each win.
- The unit test class for the `CrapsGame` class should still work with the new `CrapsPlayerPass`. Using a non-random generator for `Dice`, this should be able to confirm correct operation of the `CrapsGame` for a number of bets.

# Chapter 31. Design Cleanup and Refactoring

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We have taken an intentionally casual approach to the names chosen for our various classes and the relationships among those classes. At this point, we have a considerable amount of functionality, but it doesn't reflect our overall purpose, instead it reflects the history of its evolution. This chapter will review the design from Craps and more cleanly separate it from the design for Roulette.

We expect two benefits from the rework in this chapter. First, we expect the design to become “simpler” in the sense that Craps is separated from Roulette, and this will give us room to insert Blackjack into the structure with less disruption in the future. Second, and more important, the class names will more precisely reflect the purpose of the class, making it easier to understand the system, which means it will be easier to debug, maintain and adapt.

## Overview

We can now use our application to generate some more usable results. We would like the `Simulator` class to be able to use our Craps game, dice, table and players in the same way that we use our Roulette game, wheel, table and players. The idea would be to give the `Simulator`'s constructor Craps-related objects instead of Roulette-related objects and have everything else work normally. Since we have generally made Craps a subclass of Roulette, we are reasonably confident that this should work.

Our `Simulator`'s constructor requires a `Game` and a `Player`. Since `CrapsGame` is a subclass of `Game` and `CrapsPlayer` is a subclass of `Player`, we can construct an instance of `Simulator`.

Looking at this, however, we find a serious problem with the names of our classes and their relationships. When we designed Roulette, we used generic names like `Table`, `Game` and `Player` unwisely. Further, there's no reason for Craps to be dependent on Roulette. We would like them to be siblings, and both children of some abstract game simulation.

### Soapbox On Refactoring

We feel very strongly that our *design by refactoring* helps beginning designers produce a more functional design more quickly than the alternative approach, which is to attempt to define the game abstraction and player abstraction first and then specialize the various games. When defining an abstract superclass, some designers will build a quick and dirty design for some of the subclasses, and use this to establish the features that belong in the superclass. We find that a more successful superclass design comes from have more than one working subclasses and a clear understanding of the kinds of extensions that are likely to emerge from the problem domain.

While our approach of refactoring working code seems expensive, the total effort is often smaller. The largest impediment we've seen seems to stem from the project-management mythology that once something passes unit tests it is done for ever and can be checked off as completed. We feel that it is very important to recognized that passing a unit test is only one of many milestones. Passing an integration test, and passing the *sanity test* are better indicators of done-ness.

The sanity test is the designer's ability to explain the class structure to someone new to the project. We feel that class and package names must make obvious sense in the current project context. We find that any explanation of a class name that involves the words “historically”, or “originally” means that there are more serious design deficiencies that need to be repaired.

We now know enough to factor out the common features of `Game` and `CrapsGame` to create three new classes from these two. In order to do that, we'll have to unify `Dice` and `Wheel`, as well as `Table` and `CrapsTable` and `Player` and `CrapsPlayer`. Looking into `Dice` and `Wheel`, we see that we'll have to tackle `Bin` and `Throw` first. Unifying `Bin` and `Throw` is covered in Design Heavy. If the necessary design for `RandomEvent` is already in place, skip to Unifying Dice and Wheel. After that, we can refactor the other classes.

**Unifying Bin and Throw.** We need to create a common superclass for `Bin` and `Throw`, so that we can then create some commonality between `Dice` and `Wheel`. This unification will make the `Vector` of results and the `next` method identical.

The first step, then, is to identify what are the common features of `Bin` and `Throw`. The relatively simple `Bin` and the more complex `Throw` can be unified in one of two ways.

1. Use `Throw` as the superclass. A Roulette `Bin` doesn't need a specific list of losing `Outcomes`. Indeed, we don't even need a subclass, since a Roulette `Bin` can just ignore features of a Craps `Throw`.

2. Create a superclass based on `Bin`, make `Bin` a subclass and change `Throw` to add features to the new superclass.

The first design approach is something we call the **Swiss Army Knife** design pattern: create a structure that has every possible feature, and then ignore the features you don't need. This creates a distasteful disconnect between the use of `Bin` and the declaration of `Bin`: we only use a the Set of winning `Outcomes`, but the object has the losing Set that isn't used by anything else in the Roulette game.

We also note that a key feature of OO languages is inheritance, which *adds* features to a superclass. The **Swiss Army Knife** design approach, however, works by subtracting features. Since the languages were using don't really support class definition by subtraction, we try to ignore the features, creating a distance between the OO language and our design intent.

Our first decision, then, is to refactor `Throw` and `Bin` to make them instances of a common superclass, which we'll call `RandomEvent`. See the Craps Throw Overview for our initial thoughts on this, echoed in the Soapbox On Refactoring sidebar.

The responsibilities for `RandomEvent` are essentially the same as `Bin`. We can then make `Bin` a subclass that doesn't add any new features, and `Throw` a subclass that adds a number of features, including the value of the two dice and the Set of losing `Outcomes`. Note that we have made `Throw` and `Bin` siblings of a common superclass. See Soapbox on Architecture for more information on our preference for this kind of design.

**Unifying Dice and Wheel.** When we take a step back from `Dice` and `Wheel`, we see that they are nearly identical. They differ in the construction of the `Bins` or `Throws`, but little else. Looking forward, the deck of cards used for Blackjack is completely different. Dice and a Roulette wheel use *selection with replacement*: an event is picked at random from a pool, and is eligible to be picked again any number of timers. Cards, on the other hand, are *selection without replacement*: the cards form a sequence of events of a defined length that is randomized by a shuffle. If we have a 5-deck shoe, we can only see five kings of spades during the game, and we only have 260 cards. However, we can roll an indefinite number of 7's on the dice.

We note that there is a superficial similarity between the rather complex `BinBuilder` methods and the simpler method in `ThrowBuilder`. However, there is no compelling reason for polymorphism between these two classes. We don't have to factor these into a common class hierarchy.

Our second design decision, then, is to create a `RandomEventFactory` out of `Dice` and `Wheel`. This refactoring will make the `Vector` of results and the `next` method part of the superclass. Each subclass provides the initialization method that constructs the `Vector` of `RandomEvent`s.

When we move on to tackle cards, we'll have to create a subclass that uses a different definition of `next` and adds `shuffle`. This will allow a deck of cards to do selection without replacement.

**Refactoring Table and CrapsTable.** We see few differences between `Table` and `CrapsTable`. When we designed `CrapsTable` we had to add a relationship between `CrapsTable` and `CrapsGame` so that a table could ask the game to validate individual `Bets` based on the state of the game.

If we elevate the `CrapsTable` to be the superclass, we eliminate a need to have separate classes for Craps and Roulette. We are dangerously close to embracing a **Swiss Army Knife** design. The distinction may appear to be merely a matter of degree: one or two features can be pushed up to the superclass and then ignored in a subclass. However, in this case, both Craps and Roulette will use the `Game` to validate bets: the feature will not be ignored. It happens that the Roulette Game will permit all bets, but we have made that the Game's responsibility, not the Table's. Indeed, viewed this way, the Roulette version of Table implicitly took a responsibility away from the Roulette Game because the Table failed to collaborate with the Game for any game-state specific rules. At the time, we overlooked this nuance because we knew that Roulette was stateless and we were comfortable making that assumption part of the design.

Our third design decision is to merge `Table` and `CrapsTable` into a new `Table` class and use this for both games. This will simplify the various Game classes by using a single class of `Table` for both games.

**Refactoring Player and CrapsPlayer.** Before we can finally refactor `Game`, we need to be sure that we have sorted out a proper relationship between our various players. In this case, we have a large hierarchy, which will we hope to make far larger as we explore different betting alternatives. Indeed, the central feature of this simulation is to expand the hierarchy of players as needed to explore betting strategies. Therefore, time spent organizing the `Player` hierarchy is time well spent.

We'd like to have the following hierarchy, all subclasses of `Player`.

- RoulettePlayer.
    - RouletteMartingale.

  - RouletteRandom.
  - RouletteSevenReds.
  - Roulette1326.
  - RouletteCancellation.
  - RouletteFibonacci.
- CrapsPlayer.
  - CrapsMartingale.

Looking forward to Blackjack, see see that there is much richer player interaction, because there are player decisions that are not related to betting. This class hierarchy seems to enable that kind of expansion.

We note that there are two “dimensions” to this class hierarchy. One dimension is the game (Craps or Roulette), the other dimension is a betting system (Matingale, 1326, Cancellation, Fibonacci). For Blackjack, there is also a playing system in addition to a betting system. Sometimes this multi-dimensionsal aspect of a class hierarchy indicates that we could be using multiple inheritance. In the case of Python, we have multiple inheritance in the language, and we can pursue this directly. Java, however, demands the **Strategy** design pattern to add a flexible betting strategy object to the basic interface for playing the game.

In Roulette, where we are placing a single bet, there is almost no distinction between game interface and the betting system. However, in Craps, we made a distinction in our Martingale player by separating their Pass Line bet (where the payout doesn't match the actual odds very well) from their Pass Line Odds bet (where the payout does match the odds). This means that our Martingale Craps player really has two betting strategies objects: a flat bet strategy for Pass Line and a Martingale Bet strategy for the Pass Line Odds.

If we separate the player and the betting system, we could easily mix and match betting systems, playing systems and game rules. In the case of Craps, where we can have many working bets (Pass Line, Come Point Bets, Hardways Bets, plus Propostions), each player would have a mixture of betting strategies used for their unique mixture of working bets. This leads to an interesting issue in the composition of such a complex object. For the current exercise, however, we won't formally separate the player from the various betting strategies.

Rather than fully separate the player's game interface and betting system interface, we can simply adjust the class hierarchy and the class names to those shown above. We need to make the superclass, `Player` independent of any game. We can do this by extracting anything Roulette-specific from the original `Player` class and renaming our Roulette-focused `Passenger57` to be `RoulettePlayer`, and fix all the Roulette player subclasses to inherit from `RoulettePlayer`.

We will encounter one design difficulty when doing this. That is the dependency from the various `Player1326State` classes on a field of `Player1326`. Currently, we will simply be renaming `Player1326` to `Roulette1326`. However, as we go forward, we will see how this small issue will become a larger problem. In Python, we can easily overlook this, as described in Python and Interface Design.

### Python and Interface Design

Because of the run-time binding done in Python, there is no potential problem in having the `Player1326State` classes depend on a field of `Player1326`. Since Java checks the validity of these references at compile time, we are forced to provide proper declarations for the `outcome` field in `Player1326`. In the event of change, this declaration may no longer be valid, alterting us to a dependency. In Python, however, the attributes of an object are kept in a dictionary, which is created dynamically during execution, making it difficult to assure that one class properly includes the attributes that will be required by a collaborating class. We don't discover problems in Python until the application crashes at run time because of a missing attribute.

Some Python programmers will bypass the simple access methods and check an object's internal `__dict__` for the presence of the expected `outcome` attribute. We don't condone this: the application should crash because of design changes, not work around them.

While the dynamic nature of Python attributes has some beneficial effects, we find it can be easily abused. We consider references to the `__dict__` object to raise serious quality concerns, and discourage its use by new OO designers.

**Refactoring Game and CrapsGame.** Once we have a common `RandomEventFactory`, a common `Table`, and a common `Player`, we can separate `Game` from `RouletteGame` and `CrapsGame` to create three new classes.

- The abstract superclass, `Game`. This will contain a `RandomEventFactory`, a `Table` and have the necessary interface to reset the game and execute one cycle of play. This class is based on the existing `Game`, with the Roulette-specific `cycle` replaced with an abstract method definition.
- The concrete subclass, `RouletteGame`. This has the `cycle` method appropriate to Roulette that was extracted from the original `Game` class.
- The concrete subclass, `CrapsGame`. This has the `cycle` method appropriate to Craps. This is a small change to the parent of the `CrapsGame` class.

While this appears to be a tremendous amount of rework, it reflects lessons learned incrementally through the previous 29 chapters of exercises. This refactoring is based on considerations that would have been challenging, perhaps impossible, to explain from the outset. Since we have working unit tests for each class, this refactoring is easily validated by rerunning the existing suite of tests.

## Design

### RandomEventFactory class

`RandomEventFactory` is a superclass for Dice, Wheel, Cards, and other casino random-event generators.

#### Fields

- Java: `java.util.Vector bins = null;`

  Python: `bins = []`

  Contains the individual `RandomEvent` instances.

- Java: `java.util.Random rng ;`

  Python: `rng`

  Generates the next random number, used to select a `Bin` from the `bins` collection.

- `RandomEvent current = null;`

  The most recently returned `RandomEvent`.

### Constructors

- `RandomEventFactory(java.util.Random rng);`

  Saves the given Random Number Generator. Calls the `initialize` method to create the vector of results.

### Methods

- `abstract void initialize();`

  Creates the `results` vector with the pool of possible results. Each subclass must provide a unique implementation for this.

- `next();`

  Generates a random number between 0 and 37, and returns the randomly selected `Bin`.

  Java: Be sure to note that the `java.util.Random` `nextInt` method uses the size of the `bins` collection to return values from 0 to the size of the collection. Typically there are 38 values, numbered from 0 to 37.

  Python: the `choice` function will select one of the available `Bins` from the `bins` list.

## Wheel Class

`Wheel` is a subclass of `RandomEventFactory` that contains the 38 individual `Bins` on a Roulette wheel. As a `RandomEventFactory`, it contains a random number generator and can select a `Bin` at random, simulating a spin of the Roulette wheel.

### Fields

The fields are all inherited from `RandomEventFactory`.

### Constructors

- `Wheel();`

  Creates a new wheel with 38 empty `Bins`. It will also create a new random number generator instance. Calls `initialize` to create the `Bins`.

### Methods

-
  ```
  addOutcome(int number,
             Outcome outcome);
  ```

  Adds the given `Outcome` to the `Bin` with the given number.

- `void initialize();`

  Creates the `results` vector with the pool of possible results. This will create an instance of `BinBuilder`, `bb` and delegate the construction to the `buildBins` method of the `bb` object.

## Dice Class

`Dice` is a subclass of `RandomEventFactory` that contains the 36 individual throws of two dice. As a `RandomEventFactory`, it contains a random number generator and can select a `Throw` at random, simulating a throw of the Craps dice.

### Fields

The fields are all inherited from `RandomEventFactory`.

### Constructors

- `Dice();`

  Creates a new random number generator instance. Uses this to call this other constructor, using `this( rng );`.

- `Dice(Random rng);`

  Creates a new set of dice an empty `Map`. Saves the given random number generator instance. Calls the `initialize` method to construct the `Throws`.

### Methods

- `addOutcome(NumberPair faces,`

```
            Outcome outcome);
```

Adds the given `Outcome` to the `Throw` with the given `NumberPair`. This allows us to create a collection of several one-roll `Outcomes`. For example, a throw of 3 includes four one-roll `Outcomes`: Field, 3, any Craps, and Horn.

- `initialize();`

  Creates the 8 one-roll `Outcome` instances (2, 3, 7, 11, 12, Field, Horn, Any Craps). It then creates the 36 `Throws`, each of which has the appropriate combination of `Outcomes`.

-
  ```
  Throw getThrow(int d1,
                 int d2);
  ```

  While not needed by the application, unit tests will need a method to return a specific `Throw` rather than a randomly selected `Throw`. This method takes a particular combination of dice, creates a NumberPair, and returns the appropriate `Throw`.

## Table Class

`Table` contains all the `Bets` created by the `Player`. A table has an association with a `Game`, which is responsible for validating individual bets. A table also has betting limits, and the sum of all of a player's bets must be within this limits.

### Fields

- `int mimimum ;`

  This is the table lower limit. The sum of a `Player`'s bets must be greater than or equal to this limit.

- `int maximum ;`

  This is the table upper limit. The sum of a `Player`'s bets must be less than or equal to this limit.

- `List bets ;`

  This is a `LinkedList` of the `Bets` currently active. These will result in either wins or losses to the `Player`.

- `Game theGame ;`

  The `Game` used to determine if a given bet is allowed in a particular game state.

### Constructors

- `Table();`

  Creates an empty `LinkedList` of bets.

### Methods

- `void setGame(Game aGame);`

  Saves the given `Game` to be used to validate bets.

- `boolean isValid(Bet bet);`

  Validates this bet. The first test checks the `Game` to see if the bet is valid; it returns `false` immediately if the bet is not valid. If the bet is valid, it then checks if the sum of all bets is less than or equal to the table limit. If the bet is valid, return `true`. Otherwise, return `false`.

- `boolean allValid();`

  Validates the sum of all bets within the table limits. Returns false if the minimum is not met or the maximum is exceeded.

-
  ```
  void placeBet(Bet bet)
      throws InvalidBet;
  ```

  Adds this bet to the list of working bets. If the sum of all bets is greater than the table limit, then an exception should be thrown (Java) or raised (Python). This is a rare circumstance, and indicates a bug in the `Player` more than anything else.

- `Iterator iterator();`

  Returns an `Iterator` over the list of bets. This gives us the freedom to change the representation from `LinkedList` to any other `Collection` with no impact to other parts of the application.

  In Python, similarly, we can return an iterator over the available list of `Bet` instances. The more traditional Python approach is to return the list itself, rather than an iterator over the list. With the introduction of the *generators* in Python 2.3, however, it is slightly more flexible to return an iterator rather than the collection itself. The iterator could be built, for example, using the `yield` statement instead of the `iter` function.

- Java: `public String toString();`

  Python: `def __str__(self):`

  reports on all of the currently placed bets.

## Player class

`Player` places bets in a `Game`. This an abstract class, with no actual body for the `placeBets` method. However, this class does implement the basic `win` and `lose` methods used by all subclasses.

**Roulette Player Hierarchy.** The classes in the Roulette Player hierarchy need to have their superclass adjusted to conform to the newly-defined superclass. The former `Passenger57` is renamed to

`RoulettePlayer`. All of the various Roulette players become subclasses of `RoulettePlayer`.

In addition to renaming `Player1326` to `Roulette1326`, we will also have to change the references in the various classes of the `Player1326State` class hierarchy. We suggest leaving the class names alone, but merely changing the references within those five classes from `Player1326` to `Roulette1326`.

**Craps Player Hierarchy.** The classes in the Craps Player hierarchy need to have their superclass adjusted to conform to the newly-defined superclass. We can rename `CrapsPlayerMartigale` to `CrapsMartigale`, and make it a subclass of `CrapsPlayer`. Other than names, there should be no changes to these classes.

### Fields

- `int stake ;`

  The player's current stake. Initialized to the player's starting budget.

- `int roundsToGo ;`

  The number of rounds left to play. Initialized by the overall simulation control to the maximum number of rounds to play. In Roulette, this is spins. In Craps, this is the number of throws of the dice, which may be a large number of quick games or a small number of long-running games. In Craps, this is the number of cards played, which may be large number of hands or small number of multi-card hands.

- `Table table ;`

  Used to place individual `Bet`s.

### Constructors

- `Player(Table aTable);`

  Constructs the `Player` with a specific `Table` for placing `Bet`s.

### Methods

- `boolean playing();`

  Returns `true` while the player is still active. There are two reasons why a player may be active. Generally, the player has a `stake` greater than the table minimum and has a `roundsToGo` greater than zero. Alternatively, the player has bets on the table; this will happen in craps when the game continues past the number of rounds budgeted.

- `void placeBets();`

  Updates the `Table` with the various `Bet`s.

When designing the `Table`, we decided that we needed to deduct the amount of a bet from the stake when the bet is created. See the Table Overview for more information.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The amount of money won is available via `theBet` `winAmount`.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser.

## Game Class

`Game` manages the sequence of actions that defines casino games, including Roulette, Craps and Blackjack. Individual subclasses implement the detailed playing cycles of the games. This superclass has methods for notifying the `Player` to place bets, getting a `RandomEvent` and resolving the `Bets` actually present on the `Table`.

### Fields

- `RandomEventFactory eventFactory ;`

  Contains a `Wheel` or `Dice` or other subclass of `RandomEventFactory` that returns a randomly selected `RandomEvent` with specific `Outcomes` that win or lose.

- `Table theTable ;`

  Contains the `Bets` placed by the `Player`.

- `Player thePlayer ;`

  Places bets on the table.

### Constructors

- We based this constructor on an design that allows any of these objects to be replaced. This is the **Strategy** design pattern. Each of these objects is a replaceable strategy, and can be changed by the client that uses this game.

  Additionally, we specifically do not include the `Player` instance in the constructor. The `Game` exists independently of any particular `Player`, and we defer binding the `Player` and `Game` until we are gathering statistical samples.

  ```
  Game(RandomEventFactory anEventFactory,
       Table aTable);
  ```

  Constructs a new `Game`, using a given `RandomEventFactory` and `Table`.

### Methods

- `abstract void cycle(Player aPlayer);`

  This will execute a single cycle of play with a given `Player`. For Roulette is is a single spin of the wheel. For Craps, it is a single throw of the dice, which is only one part of a complete game. This method will call `thePlayer` `placeBets` to get bets. It will call `eventFactory` `next` to get the next Set of `Outcomes`. It will then call `theTable`'s `bets` to get an `Iterator` over the `Bets`. Stepping through this `Iterator` returns the individual `Bet` objects. The bets are resolved, calling the `thePlayer` `win`, otherwise call the `thePlayer` `lose`.

- `void reset();`

  As a useful default for all games, this will tell the table to clear all bets. A subclass can override this to reset the game state, also.

## RouletteGame Class

`RouletteGame` is a subclass of `Game` that manages the sequence of actions that defines the game of Roulette.

### Methods

- `void cycle(Player aPlayer);`

  This will execute a single cycle of the Roulette with a given `Player`. It will call `thePlayer` `placeBets` to get bets. It will call `theWheel` `next` to get the next winning `Bin`. It will then call `theTable`'s `bets` to get an `Iterator` over the `Bets`. Stepping through this `Iterator` returns the individual `Bet` objects. If the winning `Bin` contains the `Outcome`, call the `thePlayer` `win`, otherwise call the `thePlayer` `lose`.

## CrapsGame Class

`CrapsGame` is a subclass of `Game` that manages the sequence of actions that defines the game of Craps.

Note that a single cycle of play is one throw of the dice, not a complete craps game. The state of the game may or may not change.

### Methods

- `void cycle(Player aPlayer);`

  This will execute a single cycle of play with a given `Player`.

  1. It will call `thePlayer` `placeBets` to get bets. It will validate the bets, both individually, based on the game state, and collectively to see that the table limits are met.

2. It will call `theDice next` to get the next winning `Throw`.
3. It will use the `Throw`'s `updateGame` to advance the game state.
4. It will then call `theTable bets` to get an `Iterator`; stepping through this `Iterator` returns the individual `Bet` objects.
    - It will use the `Throw`'s `resolveOneRoll` method to check one-roll propositions. If the method returns true, the `Bet` is resolved and should be deleted.
    - It will use the `Throw`'s `resolveHardways` method to check the hardways bets. If the method returns true, the `Bet` is resolved and should be deleted.

- `Outcome pointOutcome();`

  Returns the `Outcome` based on the current point. This is used to create Pass Line Odds or Don't Pass Odds bets. This delegates the real work to the current `CrapsGameState` object.

-
  ```
  void moveToThrow(Bet aBet,
                   Throw theThrow);
  ```

  Moves a Come Line or Don't Come Line bet to a new `Outcome` based on the current throw. If the value of `theThrow` is 4, 5, 6, 8, 9 or 10, this delegates the move to the current `CrapsGameState` object. For other values of `theThrow`, this method does nothing.

## Deliverables

There are six deliverables for this exercise.

- If necessary, create `RandomEvent`, and revisions to `Throw` and `Bin`. See Design Heavy.
- Create `RandomEventFactory`, and associated changes to `Wheel` and `Dice`. The existing unit tests will confirm that this change has no adverse effect.
- Refactor `Table` and `CrapsTable` to make a single class of these two. The unit tests for the original `CrapsTable` should be merged with the unit tests for the original `Table`.
- Refactor `Player` and `CrapsPlayer` to create a better class hierarchy with `CrapsPlayer` and `RoulettePlayer` both sibling subclasses of `Player`. The unit tests should confirm that this change has no adverse effect.
- Refactor `Game` and `CrapsGame` to create three classes: `Game`, `RouletteGame` and `CrapsGame`. The unit tests should confirm that this change has no adverse effect.
- Create a new main program class that uses the existing `Simulator` with the `CrapsGame` and `CrapsPlayer` classes.

# Chapter 32. Simple Craps Players

**Table of Contents**

This chapter defines a variety of player strategies. Most of this is based on strategies already defined in Part I, “Roulette”, making the explanations considerably simpler. Rather than cover each individual design in separate chapters, we'll rely on the experience gained so far, and cover four variant Craps players in this chapter. We'll mention a fifth, but leave that as a more advanced exercise.

## Overview

When we looked at our `Player` hierarchy, we noted that we could easily apply a number of strategies to the Pass Line Odds bet. We use the Martingale strategy for our `CrapsMartingale` player. We could also use the 1-3-2-6 system, the Cancellation system, or the Fibonacci system for those odds bets. In each of these cases, we are applying the betting strategy to one of the two bets the player will use.

An additional design note for this section is the choice of the two basic bets: the Pass Line and the Pass Line Odds bet. It is interesting to compare the results of these bets with the results of the Don't Pass Line and the Don't Pass Odds Bet. In particular, the Don't Pass Odds Bets involve betting large sums of money for small returns; this will be compounded by any of these betting systems which accelerate the amount of the bet to cover losses. This change should be a simple matter of changing the two base bets used by all these variant players.

All of these players have a base bet (either Pass Line or Don't Pass) and an odds bet (either Pass Line Odds or Don't Pass Odds). If we create a superclass, called `SimpleCraps`, we can assure that all these simple betting variations will work for Pass Line as well as Don't Pass Line bets. The responsibility of this superclass is to define a consistent set of fields and constructor for all of the subclasses.

**Craps 1-3-2-6.** This player uses the 1-3-2-6 system for managing their odds bet. From the Roulette 1-3-2-6 Overview, we can see that this player will need to use the `Player1326State` class hierarchy. The craps player will use one of these objects track the state changes of their odds. The base bet will not change.

However, the current definitions of the `Player1326State` class hierarchy specifically reference `Roulette1326`. Presenting us with an interesting design problem. How do we repair our design so that `Player1326State` can work with `Roulette1326` and `Craps1326`? The only dependency is the field `outcome`, which both `Roulette1326` and `Craps1326` must provide to `Player1326State` objects. We have three choices: extract the field and make it part of an interface, refactor the field up to the superclass, change the defintion of `Player1326State` to make it more self-contained.

- **Common Interface.** The relationship between a subclass of `Player` and `Player1326State` can be formalized through an interface. We could define something like `Bet1326able`, and use this for `Roulette1326` and `Craps1326`. In this case, this appears to be an example of the **Very Large Hammer** design pattern. The problem seems too small for this language feature.

- **Common Superclass.** Refactoring the single instance variable up to the superclass makes a relatively minor change. However, it places a feature in the superclass which all but a few subclasses must ignore. This is another example of **Swiss Army Knife** design, where we will be subtracting a feature from a superclass.

- **Delegate.** If we change the `Player1326State` class to keep its own copy of the desired `Outcome` we cleanly remove any dependence on `Player`. The `Player` is still responsible for keeping track of the `Outcomes`, and has subcontracted or delegated this responsibility to an instance of `Player1326State`. The down side of this is that we must provide this `Outcome` to each state constructor as the state changes.

The solution we embrace is changing the definition of `Player1326State` to include the `Outcome`. This delegates responsibility to the state, where it seems to belong. This will change all of the constructors, and all of the state change methods, but will cleanly separate the `Player1326State` class hierarchy from the `Player` class hierarchy.

**Craps Cancellation.** When can examine the Roulette Cancellation Overview and see that this player will need to use a List of individual betting amounts. Each win for an odds bet will cancel from this List, and each loss of an odds bet will append to this List.

As with the Craps Martingale player, we will be managing a base Pass Line bet, as well as an odds bet that uses the Cancellation strategy. The Cancellation algorithm can be easily transplanted from the original Roulette version to this new Craps version.

**Craps Fibonacci.** When can examine the Roulette Fibonacci Overview and see that this player will need to compute new betting amounts based on wins and losses.

## Design

We'll extend `CrapsPlayer` to create a `CrapsSimplePlayer` that can place both Pass Line and Pass Line Odds bets, as well as Don't Pass Line and Don't Pass Odds bets. This will allow us to drop the `CrapsPlayerPass` class, and revise the existing `CrapsMartingale`

We have to rework the original Roulette-focused `Player1326State` hierarchy, and the `Roulette1326` class to use the new version of the state objects.

Once this rework is complete, we can add our `Craps1326` and `CrapsCancellation` players.

For additional exposure, the more advanced student can rework the Roulette Fibonacci player to create a `CrapsFibonacci` player.

## CrapsSimplePlayer superclass

`CrapsSimplePlayer` is a subclass of `CrapsPlayer` and places two bets in Craps. The simple player has a base bet and an odds bet. The base bet is one of the bets available on the come out roll (either Pass Line or Don't Pass Line), the odds bet is the corresponding odds bet (Pass Line Odds or Don't Pass Odds). This class implements the basic procedure for placing the line bet and the behind the line odds bet. However, the exact amount of the behind the line odds bet is left as an abstract method. This allows subclasses to use any of a variety of betting strategies, including Martingale, 1-3-2-6, Cancellation and Fibonacci.

### Fields

- `Outcome lineOutcome ;`

  The player's line, either Pass Line or Don't Pass Line.

- `Outcome odds ;`

  The odds bet that matches the line bet. Either Pass Line Odds or Don't Pass Odds.

### Constructors

-
  ```
  CrapsSimplePlayer(Table aTable,
                    Outcome line,
                    Outcome odds);
  ```

  Constructs the `CrapsSimplePlayer` with a specific `Table` for placing `Bets`. Additionally the line bet (Pass Line or Don't Pass Line) and odds bet (Pass Line Odds or DOn't Pass Odds) are provided to this constructor. This allows us to make either Pass Line or Don't Pass Line players.

### Methods

- `void placeBets();`

  Updates the `Table` with the various `Bets`. There are two basic betting rules.

  1. If there is no line bet, create the line `Bet` from the `line Outcome`.
  2. If there is no odds bet, use the `oddsBet` method to create odds `Bet` from the `odds Outcome`.

  Be sure to check the price of the `Bet` before placing it. Particularly, Don't Pass Odds bets may have a price that exceeds the player's stake. This means that the `Bet` object must be constructed, then the price must be tested against the `stake` to see if the player can even afford it. If the `stake` is greater than or equal to the price, subtract the price and place the bet. Otherwise, simply ignore it.

- `abstract Bet oddsBet();`

  A subclass will override this for a given betting strategy to create the `Bet` from the `odds Outcome`.

The Martingale player, for instance, doubles the multiplier on each loss, and resets it to 1 on each win.

## Craps Martingale Player

`CrapsMartingale` is a subclass of `CrapsSimplePlayer` who places bets in Craps. This player doubles their Pass Line Odds bet on every loss and resets their Pass Line Odds bet to a base amount on each win.

### Fields

- `int lossCount ;`

  The number of losses. This is the number of times to double the pass line odds bet.

- `int betMultiple ;`

  The the bet multiplier, based on the number of losses. This starts at 1, and is reset to 1 on each win. It is doubled in each loss. This is always equal to $2^{lossCount}$.

### Methods

- `Bet oddsBet();`

  Returns a new `Bet` using the `odds` outcome and the value of `betMultiple`.

- `void win(Bet theBet);`

  Uses the superclass `win` method to update the stake with an amount won. This method then resets `lossCount` to zero, and resets `betMultiple` to `1`.

- `void lose(Bet theBet);`

  Increments `lossCount` by `1` and doubles `betMultiple`.

## Player1326 State

`Player1326State` is the superclass for all of the states in the 1-3-2-6 betting system.

### Fields

- `Outcome outcome ;`

  The `Outcome` on which we will bet.

### Constructors

- `Player1326State(Outcome outcome);`

The constructor saves the desired `Outcome`.

### Methods

- `abstract Bet currentBet();`

  Constructs a new `Bet` from the `outcome` information. Each subclass has a different multiplier used when creating this bet.

  In Java, this method can be declared as abstract. Each subclass will provide a unique implementation for this method.

  In Python, this method should raise the `NotImplementedException`. This is a big debugging aid, it helps us locate subclasses which did not provide a method body. This raise statement is the functional equivalent of the Java abstract declaration.

- `abstract Player1326State nextWon();`

  Constructs the new `Player1326State` instance to be used when the bet was a winner. This will use the `outcome` to be sure the new state knows the `Outcome` on which we are betting.

  In Java, this method can be declared as abstract. Each subclass will provide a unique implementation for this method.

  In Python, this method should raise the `NotImplementedException`.

- `Player1326State nextLost();`

  Constructs the new `Player1326State` instance to be used when the bet was a loser. This method is the same for each subclass: it creates a new instance of `Player1326NoWins`. It is not abstract, but actually defined in the superclass to assure that it is available for each subclass. This will use the `outcome` to be sure the new state knows the `Outcome` on which we are betting.

## Craps1326 Player

`Craps1326` is a subclass of `CrapsSimplePlayer` who places bets in Craps. This player changes their Pass Line Odds bet on every loss and resets their Pass Line Odds bet to a base amount on each win. The sequence of bet multipliers is given by the current `Player1326State` object.

### Fields

- `Player1326State myState = null;`

  This is the current state of the 1-3-2-6 betting system. It will be an instance of one of the four states: No Wins, One Win, Two Wins or Three Wins.

### Constructors

-
  ```
  Craps1326(Table aTable,
            Outcome line,
            Outcome odds);
  ```

  Uses the superclass to initialize the `Craps1326` with a specific `Table` for placing `Bets`, and set the line bet (Pass Line or Don't Pass Line) and odds bet (Pass Line Odds or Don't Pass Odds). Then the initial state of `Player1326NoWins` is constructed using the odds bet.

### Methods

- `Bet oddsBet();`

  Returns a new `Bet` using the `currentBet` method from the `myState` object.

- `void win(Bet bet);`

  Uses the superclass method to update the stake with an amount won. Uses the current state to determine what the next state will be by calling `myState`'s `nextWon` method and saving the new state in `myState`

- `void lose(Bet bet);`

  Uses the current state to determine what the next state will be. This method delegates the next state decision to `myState`'s `nextLost`, method saving the result in `myState`.

## CrapsCancellation Player

`CrapsCancellation` is a subclass of `CrapsSimplePlayer` who places bets in Craps. This player changes their Pass Line Odds bet on every win and loss using a budget to which losses are appended and winings are cancelled.

### Fields

- `List sequence = new List();`

  This `List` keeps the bet amounts; wins are removed from this list and losses are appended to this list. THe current bet is the first value plus the last value.

### Constructors

-
  ```
  CrapsCancellation(Table aTable,
                    Outcome line,
                    Outcome odds);
  ```

  Invokes the superclass constructor to initialize this instance of `CrapsCancellation`. Then calls `resetSequence` to create the betting budget.

### Methods

- `resetSequence();`

  Puts the initial sequence of six `Integer` instances into the `sequence` variable. These `Integers` are built from the values 1 through 6.

- `Bet oddsBet();`

  Returns a new `Bet` using the preferred outcome in `odds` and the amount given by the sum of the first and last values of `sequence`.

- `void win(Bet bet);`

  Uses the superclass method to update the stake with an amount won. It then removes the fist and last element from `sequence`.

- `void lose(Bet bet);`

  Uses the superclass method to update the stake with an amount lost. It then appends the sum of the first and list elements of `sequence` to the end of `sequence` as a new `Integer` value.

## Deliverables

There are eight deliverables for this exercise.

- The `CrapsSimplePlayer` abstract superclass. Since this class doesn't have a body for the `oddsBet` method, it can't be unit tested directly.
- A revised `CrapsMartingale` class, that is a proper subclass of `CrapsSimplePlayer`. The existing unit test for `CrapsMartingale` should continue to work correctly after these changes.
- A revised `Player1326State` class hierarchy. Each subclass will use the `outcome` field instead of getting this information from a `Player1326` instance. The unit tests will have to be revised slightly to reflect the changed constructors for this class.
- A revised `Roulette1326` class, which reflects the changed constructors for this `Player1326State`. The unit tests should indicate that this change has no adverse effect.
- The `Craps1326` subclass of `CrapsSimplePlayer`. This will use the revised `Player1326State`.
- A unit test class for `Craps1326`. This test should synthesize a fixed list of `Outcomes`, `Throws`, and calls a `Craps1326` instance with various sequences of craps, naturals and points to assure that the bet changes appropriately.
- The `CrapsCancellation` subclass of `CrapsSimplePlayer`.
- A unit test class for `CrapsCancellation`. This test should synthesize a fixed list of `Outcomes`,

`Throws`, and calls a `CrapsCancellation` instance with various sequences of craps, naturals and points to assure that the bet changes appropriately.

# Chapter 33. Roll-Counting Player

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## Overview

There is a distinction between one-roll odds and cumulative odds. The one roll odds of rolling a 7 are 1/6. This means that a Pass Line bet will win one time in six on the come out roll. The cumulative odds of rolling a 7 on a number of rolls depends on not rolling a seven (a 5/6 chance) for some number of rolls, followed by rolling a 7. The odds are given in the following table.

| Number of Throws | Rule | Odds of Rolling 7 |
|---|---|---|
| 1 | 1/6 | 17% |
| 2 | 5/6 * 1/6 | 31% |
| 3 | $(5/6)^2$ * 1/6 | 42% |
| 4 | $(5/6)^3$ * 1/6 | 52% |
| 5 | $(5/6)^4$ * 1/6 | 60% |
| 6 | $(5/6)^5$ * 1/6 | 67% |

This cumulative chance of rolling a 7 means that the odds of the game ending with a loss because of throwing a 7 grow as the game progresses. We can compute the following sequence of odds of losing for larger numbers of rolls of the dice after the point is established: 17%, 28%, 35%, 40%, 43%, 46%, 47%, 48%, 49%. The idea is that the longer a game runs, the more likely you are to lose your initial Pass Line bet. Consequently, some players count the thows in the game, and effectively cancel their bet by betting against themselves on the Seven proposition. Note that the Seven proposition is a 1/6 probability that pays “5 for 1”, which is actually 4:1.

While the basic probability analysis of this bet is not encouraging, it does have an interesting design problem: the player now has multiple states. They have Pass Line bet, they can use a Martingale strategy for their Pass Line Odds bet, they are counting throws, and they are using a Martingale strategy for a Seven proposition starting with the seventh throw of the game.

We also note that this analysis doesn't work for wrong bettors using the Don't Pass Line bet. Their concern is the opposite: a short game may cause them to lose their Don't Pass bet, but a long game makes it more likely that they would win. One simulation for this is to place Don't Pass Odds bets after several throws, where the odds bet appears more likely to win.

This leads us to consider the player as a composite object with a number of states and strategies. It also leads us to design a class just to handle Martingale betting. Note that when we were looking at the design for the various players in Design Cleanup and Refactoring, we glanced at the possibility of separating the individual betting strategies from the players, and opted not to. However, we did force each strategy to depend on a narrowly-defined interface of `oddsBet`, `won` and `lost`. We can exploit this narrow interface in teasing apart the various strategies and rebuilding each variation of `Player` with a distinct betting strategy object.

The separation of `Player` from `BettingStrategy` involves taking the betting-specific information out of each player class, and replacing the various methods and fields with one or more `BettingStrategy` objects. In the case of Roulette players, this is relatively simple. In the case of Craps players, we note that we have two bets, one with a trivial-case betting strategy where the bet never changes. If we add this `NoChange` strategy, we can redefine all Craps player's bets using `BettingStrategy` objects.

The responsibilities of a `BettingStrategy` are to maintain a preferred `Outcome`, maintain a bet amount, and change that amount in response to wins and losses. The existing `win` and `lose` methods are a significant portion of these reponsibilities. The `oddsBet` method of the various `CrapsSimplePlayer` embodies other parts of this, however, the name is inappropriate and it has a poorly thought-out dependency on `Player`.

The responsibilities of a `Player` are to keep one or more betting strategies, so as to place bets in a `Game`. All of the Roulette players will construct a single `BettingStrategy` object with their preferred `Outcome`. The various `CrapsSimplePlayer` classes will have two `BettingStrategys`: one for the line bet and one for the odds bet. The only difference among the simple strategies is the actual `BettingStrategy` object, simplifying the `Player` class hierarchy to a single Roulette player and two kinds of Craps players: the stub player who makes only one bet and the other players who make more than one bet and use a betting strategy for their odds bet.

Once we have this design in place, our `SevenCounter` player can then be composed of a Pass Line bet, a Pass Line Odds bet, and a Seven proposition bet that will only be used after seven rolls have passed in a single game. The line bet uses the `NoChange` strategy. The other two bets can use any of the strategies we have built: Martingale, 1326 or Cancellation.

Currently, there is no notification to the `CrapsPlayer` of unresolved bets. The player is only told of winners and losers. The opportunity to place bets indicates that the dice are being rolled. Additionally, the ability to place a line bet indicates that a game is beginning. We can use these two conditions to count the throws in during a game, effectively counting unresolved bets.

# Design

## BettingStrategy Class

`BettingStrategy` is the abstract superclass for all betting strategies. It contains a single `Outcome`, tracks wins and losses of `Bets` built on this `Outcome`, and computes a bet amount based on a specific betting strategy.

### Fields

- `Outcome outcome ;`

  This is the `Outcome` that will be watched for wins and losses, as well as used to create new `Bets`.

### Constructors

- `BettingStrategy(Outcome outcome);`

  Initializes this betting strategy with the given `Outcome`.

### Methods

- `abstract Bet createBet();`

  Returns a new `Bet` using the `outcome` `Outcome` and any other internal state of this object.

- `abstract void win(Bet theBet);`

  Notification from the `Player` that the `Bet` was a winner. The `Player` has responsibility for handling money, this class has responsibility for tracking bet changes.

- `abstract void lose(Bet theBet);`

  Notification from the `Player` that the `Bet` was a loser.

- `public String toString();`

  Returns a string with the name of the class and appropriate current state information. For the superclass, it simply returns the name of the class. Subclasses will override this to provide subclass-specific information.

## NoChangeBetting Class

`NoChangeBetting` is a subclass of `BettingStrategy` that uses a single, fixed amount for the bet. This is useful for unit testing, for modeling simple-minded players, and for line bets in Craps.

### Fields

- `int betAmount = 1;`

  This is the amount that will be bet each time.

### Constructors

- `NoChangeBetting(Outcome outcome);`

  Uses the superclass initializer with the given `Outcome`.

### Methods

- `Bet createBet();`

  Returns a new `Bet` using the `outcome` `Outcome` and `betAmount`.

- `void win(Bet theBet);`

  Does nothing.

- `void lose(Bet theBet);`

  Does nothing.

- `public String toString();`

  Returns a string with the name of the class, `outcome` and `betAmount`.

## MartingaleBetting Class

`MartingaleBetting` is a subclass of `BettingStrategy` that doubles the bet on each loss, hoping to recover the entire loss on a single win.

### Fields

- `int lossCount ;`

  The number of losses. This is the number of times to double the pass line odds bet.

- `int betMultiple ;`

  The the bet multiplier, based on the number of losses. This starts at 1, and is reset to 1 on each win. It is doubled in each loss. This is always equal to $2^{lossCount}$.

### Constructors

- `MartingaleBetting(Outcome outcome);`

  Uses the superclass initializer with the given `Outcome`.

### Methods

- `abstract Bet createBet();`

  Returns a new `Bet` using the `outcome` `Outcome` and the `betMultiple`.

- `void win(Bet theBet);`

  Resets `lossCount` to zero, and resets `betMultiple` to `1`.

- `void lose(Bet theBet);`

  Increments `lossCount` by `1` and doubles `betMultiple`.

- `public String toString();`

  Returns a string with the name of the class, `outcome` and `betMultiple`.

## Bet1326Betting Class

`Bet1326Betting` is a subclass of `BettingStrategy` that advances the bet amount through a sequence of multipliers on each win, and resets the sequence on each loss. The hope is to magnify the gain on a sequence of wins.

### Fields

- `Outcome outcome ;`

  This is the `Outcome` that will be watched for wins and losses, as well as used to create new `Bet`s.

- `Player1326State myState = null;`

  This is the current state of the 1-3-2-6 betting system. It will be an instance of one of the four states: No Wins, One Win, Two Wins or Three Wins.

### Constructors

- `Bet1326Betting(Outcome outcome);`

  Initializes this betting strategy with the given `Outcome`. Creates an initial instance of `Player1326NoWins` using `outcome`.

### Methods

- `Bet createBet();`

  Returns a new `Bet` using the `currentBet` method from the `myState` object.

- `abstract void win(Bet theBet);`

  Determines the next state when the bet is a winner. Uses `myState`'s `nextWon` method and saves the new state in `myState`.

- `void lose(Bet theBet);`

  Determines the next state when the bet is a loser. Uses `myState`'s `nextLost`, method saving the result in `myState`.

- `public String toString();`

  Returns a string with the name of the class, `outcome` and `myState`.

## CrapsOneBetPlayer class

`CrapsOneBetPlayer` is a subclass of `CrapsPlayer` and places one bet in Craps. The single bet is one of the bets available on the come out roll (either Pass Line or Don't Pass Line). This class implements the basic procedure for placing the line bet, using an instance of `BettingStrategy` to adjust that bet based on wins and losses.

### Fields

- `BettingStrategy lineStrategy ;`

  The betting strategy for the line bet. Typically, this is an instance of `NoChangeBetting`.

### Constructors

-
  ```
  CrapsOneBetPlayer(Table aTable,
                    BettingStrategy line);
  ```

  Constructs the `CrapsOneBetPlayer` with a specific `Table` for placing `Bets`. This will save the given `BettingStrategy` in `lineStrategy`.

### Example 33.1. Java Creation of A Player

```
Outcome passLine= new Outcome( "Pass Line", 1 ); ❶
BettingStrategy bet= new MartingaleBetting( passLine );  ❷
CrapsOneBetPlayer passLineMartin= new CrapsOneBetPlayer( bet ); ❸
```

❶ Creates the basic Pass Line outcome.

❷ Creates a Martingale betting strategy focused on the basic Pass Line outcome.

❸ Creates a one-bet player, who will employ the Martingale betting strategy focused on the basic Pass Line outcome.

### Methods

- `void placeBets();`

  Updates the `Table` with the various `Bet`s. There is one basic betting rule.

  1. If there is no line bet, create the line `Bet` from the `lineStrategy`.

  Be sure to check the price of the `Bet` before placing it. Particularly, Don't Pass Odds bets may have a price that exceeds the player's stake. This means that the `Bet` object must be constructed, then the price must be tested against the `stake` to see if the player can even afford it. If the `stake` is greater than or equal to the price, subtract the price and place the bet. Otherwise, simply ignore it.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The amount of money won is available via `theBet` `winAmount`. If the bet's `Outcome` matches the `lineStrategy`'s `Outcome`, notify the strategy, by calling the `lineStrategy`'s `win` method.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser. If the bet's `Outcome` matches the `lineStrategy`'s `Outcome`, notify the strategy, by calling the `lineStrategy`'s `lose` method.

## CrapsTwoBetPlayer class

`CrapsTwoBetPlayer` is a subclass of `CrapsOneBetPlayer` and places one or two bets in Craps. The base bet is one of the bets available on the come out roll (either Pass Line or Don't Pass Line). In addition to that, an odds bet (either Pass Line Odds or Don't Pass Odds) can also be placed. This class implements the basic procedure for placing the line and odds bets, using two instances of `BettingStrategy` to adjust the bets based on wins and losses.

Typically, the line bet uses an instance of `NoChangeBetting`.

### Fields

- `BettingStrategy oddsStrategy ;`

  The betting strategy for the odds bet.

### Constructors

- `CrapsTwoBetPlayer(Table aTable,`

```
                    BettingStrategy line,
                    BettingStrategy odds);
```

Uses the superclass constructor to save the game and the line bet. Then this constructor saves the odds bet `BettingStrategy`.

### Methods

- `void placeBets();`

  Updates the `Table` with the various `Bets`. There are two basic betting rules.

  1. If there is no line bet, create the line `Bet` from the `lineStrategy`.
  2. If there is no odds bet, create the odds `Bet` from the `oddsStrategy`.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The superclass handles the money won and the line bet notification. This subclass adds a comparison between the bet's `Outcome` and the `oddsStrategy`'s `Outcome`; if they match, it will notify the strategy, by calling the `oddsStrategy`'s `win` method.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser. The superclass handles the line bet notification. If the bet's `Outcome` matches the `oddsStrategy`'s `Outcome`, notify the strategy, by calling the `oddsStrategy`'s `lose` method.

## CrapsSevenCountPlayer class

`CrapsSevenCountPlayer` is a subclass of `CrapsTwoBetPlayer` and places up to three bets in Craps. The base bet is a Pass Line bet. In addition to that, a Pass Line Odds bet can also be placed. If the game runs to more than seven throws, then the “7” proposition bet (at 4:1) is placed, using the Martingale strategy.

The Pass Line bet uses an instance of `NoChangeBetting`. The Pass Line Odds bet uses an instance of `Bet1326Betting`.

### Fields

- `BettingStrategy sevenStrategy ;`

  The betting strategy for the seven bet.

- `int throwCount ;`

  The number of throws in this game. This is set to zero when we place a line bet, and incremented each time we are allowed to place bets.

### Constructors

- `CrapsSevenCountPlayer(Table aTable);`

  This will create a `NoChangeBetting` strategy based on the Pass Line `Outcome`. It will also create a `MartingaleBetting` strategy based on the Pass Line Odds `Outcome`. These will be given to the superclass constructor to save the game, the line bet and the odds bet. Then this constructor creates a `Bet1326Betting` strategy for the Seven Proposition `Outcome`.

### Methods

- `void placeBets();`

  Updates the `Table` with the various `Bets`. There are three basic betting rules.

  1. If there is no line bet, create the line `Bet` from the `lineStrategy`. Set the `throwCount` to zero.
  2. If there is no odds bet, create the odds `Bet` from the `oddsStrategy`.
  3. If the game is over seven throws and there is no seven proposition bet, create the proposition `Bet` from the `sevenStrategy`.

  Each opportunity to place bets will also increment the `throwCount` by one.

- `void win(Bet theBet);`

  Notification from the `Game` that the `Bet` was a winner. The superclass handles the money won and the line and odds bet notification.

- `void lose(Bet theBet);`

  Notification from the `Game` that the `Bet` was a loser. The superclass handles the line and odds bet notification.

## Deliverables

There are two groups of deliverables for this exercise. The first batch of deliverables are the new Betting Strategy class hierarchy and unit tests. The second batch of deliverables are the two revised Craps Player classes, the final Roll Counter Player, and the respective unit tests.

Also, note that these new classes make the previous `CrapsSimplePlayer`, `CrapsMartingale`, `Craps1326` and `CrapsCancellation` classes obsolete. There are two choices for how to deal with this change: remove and reimplement. The old calsses can be removed, and the Simulator reworked to use the new versions. The alternative is to reimplement the original classes as **Facade** over the new classes.

**Betting Strategy class hierarchy.** There are four classes, each with an associated unit test in this group of deliverables.

- The `BettingStrategy` superclass. This class is abstract; there is no unit test.
- The `NoChangeBetting` class.
- A unit test for the `NoChangeBetting` class. This will simply confirm that the `win` and `lose` methods do not change the bet amount.
- The `MartingaleBetting` class.
- A unit test for the `MartingaleBetting` class. This will confirm that the `win` method resets the bet amount and `lose` method doubles the bet amount.
- The `Bet1326Betting` class.
- A unit test for the `Bet1326Betting` class. This will confirm that the `win` method steps through the various states, and the `lose` method resets the state.

**CrapsPlayer class hierarchy.** There are three classes, each with an associated unit test in this group of deliverables.

- The `CrapsOneBetPlayer` class.
- A unit test for the `CrapsOneBetPlayer` class. One test can provide a No Change strategy for a Pass Line bet to verify that the player correctly places Line bets. Another test can provide a Martingale strategy for a Pass Line bet to verify that the player correctly changes bets on wins and losses.
- The `CrapsTwoBetPlayer` class.
- A unit test for the `CrapsTwoBetPlayer` class. One test can provide a No Change strategy for a Pass Line bet and a Martingale strategy for a Pass Line Odds bet to verify that the player correctly places Line bets and correctly changes bets on wins and losses.
- The `CrapsSevenCountPlayer` class.
- A unit test for the `CrapsSevenCountPlayer` class. This will require a lengthy test procedure to assure that the player correctly places a Seven proposition bet when the game is over seven throws long.

# Chapter 34. Conclusion

The game of Craps has given us an opportunity to extend and modify an application with a considerable number of classes and objects. It is large, but not overly complex, and produces interesting results. Further, as a maintenance and enhancement exercise, it gave us an opportunity to work from a base of software, extending and refining the quality of the design.

We omitted exercises which would integrate this package with the `Simulator` and collect statistics. This step, while necessary, doesn't include many interesting design decisions. The final deliverable should be a working application that parses command-line parameters, creates the required objects, and creates an instance of `Simulator` to collect data.

We note that many design decisions required us to explore a great deal of the overall application's design. In writing this part, we found it very difficult to stick to our purpose of building up the design using realistic steps and realistic problem solving. One purpose of this book is to avoid simply describing an already-completed design; we feel that such a description does not help new designers learn the process of design, and does not help people to identify design problems and correct them. Because of that philosophy, the complete refactoring of the design in the Design Cleanup and Refactoring chapter was something that we needed to position in a realistic context. Our observation is that this kind of design rework happens late in the life of a project, and project managers are uncomfortable evaluating the cost and benefit of the change.

Perhaps, the most important lesson that we have is the constant search for something we call *The Big Simple*. We see the history of science as a search for simpler explanations of natural phenomena. The canonical example of this is the distinction between the geocentric model and the heliocentric model of the solar system. Both can be made to work: astronomers carefully built extremely elaborate models of the geocentric heavens and produced accurate predictions of planetary positions. However, the model of planetary motion around the sun describes real phenomena more accurately and has the added benefit of being much simpler than competing models.

To continue this rant, we find that software designers and their managers do not feel the compulsion and do not budget the time to identify the grand simplification that is possible. In some cases, the result of simplifying the design on one axis will create more classes. Designers lack a handy metric for “understandability”; managers are able to count individual classes, no matter how transparently simple. Designers often face difficulties in defending a design with many simple classes; some people feel that a few complex classes is “simpler” because it has fewer classes.

As our trump card, we reference the metrics for complexity. McCabe's Cyclomatic Complexity penalizes if-statements. By reducing the number of if-statements to just those required to create an object of the proper class, we reduce the complexity. The Halstead metrics penalize programs with lots of internal operators and operands when compared with the number of operands in the interface. Halstead measures simple, transparent classes as less complex. Neither measure penalizes overall size in lines of code, but rather they penalize decision-making and hidden, internal state. A badly designed, complex class has hidden internal states, often buried in nested if-statements. We emphasize small, simple classes with no hidden features.

Our concrete examples of this simplification process are contained in three large design exercises. In Chapter 26, *Throw Builder Class*, we showed a kind of rework necessary to both generalize and isolate the special processing for Craps. In Chapter 31, *Design Cleanup and Refactoring*, we reworked classes to create an easy-to-explain architecture with layers and partitions of responsibility. Finally, in Chapter 33, *Roll-Counting Player*, we uncovered a clean separation between game rules and betting strategies.

# Blackjack

This part describes the more complex game of Blackjack. This game has a number of states and a number of complex state-change rules. It has very few different kinds of bets, but moderately complex rules for game play. However, it does have the most sophisticated playing strategy, since the player has a number of choices to make.

The chapters of this part presents the details on the game, an overview of the solution, and a series of six relatively complex exercises to build a complete simulation of the game. In the case of Blackjack, we have to create a design that allows for considerable variation in the rules of the game as well as variation in the player's betting strategies.

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# Chapter 35. Blackjack Details

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In the first section we will present elements of the game of Blackjack. Blackjack uses cards and has fairly complex rules for counting the number of points in a hard of cards.

Blackjack offers relatively few bets, most of which are available based on the state of the game. We'll cover these bets and the conditions under which they are allowed in the second sectionj.

Finally, we will describe some common betting and playing strategies that we will simulate. In this case, we have playing strategies that are unique to Blackjack, combined with betting strategies initially defined in Part I, "Roulette" and reworked in Part II, "Craps".

## Blackjack Game

Blackjack centers around *hands* composed of *cards* drawn from one or more standard 52-card *decks*. The standard deck has 13 *ranks* in 4 *suits*; the suit information has no bearing on game play. The player and the house are both dealt hands, starting with two cards. The house has one card exposed (the *up card*) and one card concealed (the *hole card*), leaving the player with incomplete information about the state of the game. The player's objective is to make a hand that has more points than the dealer, but less than or equal to 21 points. The player is responsible for placing bets when they are offered, and taking additional cards to complete their hand. The dealer will draw additional cards according to a simple rule: when the dealer's hand is 16 or less, they will draw cards (or *hit*), when it is 17 or more, they will not draw additional cards (or *stand pat*).

An interesting complication is the point values of the cards. The number cards (2-10) have the expected point values. The face cards (Jack, Queen and King) all have a value of 10 points. The Ace can count as one point or eleven points. Because of this, an Ace and a 10 or face card totals 21. This two-card winner is called "blackjack". Also, when the points include an ace counting as 11, the total is called *soft*; when the ace counts as 1, the total is called *hard*. For example, A-5 is called a soft 16 because it could be considered a hard 6. A-10-5 is a hard 16.

The betting surface is marked with two places for bets: a single bet, placed before any cards are dealt, and an insurance bet, offered only when the dealer's up card is an ace. There are a few additional bets, and a few player choices. We'll step through some variations on the sequence of play to see the interactions a player has during a game. Note that a casino table seats a number of players; like Craps and Roulette, the player opposes the house, and the presence or absence of other players has no bearing on the game.

### Note

There are seemingly endless variations in the exact playing rules used by different casinos. We'll focus on a relatively common version of the rules. With this as a basis, a number of variations can be explored.

**Typical Scenario.** The player places an initial bet. Since the bet is "blind", it is like an ante in poker. The player and dealer are each dealt a pair of cards. Both of the player's are face up, the dealer has one card up and one card down. If the dealer's card is an ace, the player is offered insurance. The details will be described in a separate sceanario, Dealer Shows An Ace.

Initially, the player has a number of choices. If the two cards are the same rank, the player can elect to split into two hands. This is a separate scenario, described in Split Hands. The player can double their bet and take just one more card. In some casinos this opportunity may be limited to certain totals on the cards, for instance, only 10 and 11; or it may be limited to a certain number of cards, for instance, two cards. The more typical scenario is for the player to take additional cards (a *hit*) until either their hand totals more than 21 (they *bust*), or their hand totals exactly 21, or they elect to stand.

If the player's hand is over 21, their bet is resolved immediately as a loss. Resolving these bets early is an important part of the house's edge in Blackjack. If the player's hand is 21 or less, however, it will be compared to the dealer's hand for resolution.

The dealer then reveals the hole card and begins taking cards according to their fixed rule. When their total is 16 or less, they take an additional card; if their total is 17 or more, they stand pat. This rule is summarized as "hit on 16, stand on 17". In some casinos a dealer will hit a soft 17 (A-6), which improves the house's edge slightly.

If the dealer busts, the player wins. If the dealer did not bust, then the hands are compared: if the player's total is more than the dealer, the player wins; if the totals are equal, the bet is a push; otherwise the player loses.

If the player's hand is an ace and a 10-point card (10, Jack, Queen or King), the hand is blackjack and the the ante is paid off at 3:2. Otherwise, winning hands that are not blackjack are paid off at 1:1.

**Dealer Shows An Ace.** If the dealer's up card is an ace, the player is offered an insurance bet. This is an additional proposition that pays 2:1 if the dealer's hand is exactly 21 (a 4/13 probability). The amount of the bet is half the original ante. If this insurance bet wins, it will, in effect, cancel the loss of the ante. After offering insurance to the player, the dealer will check their hole card and resolve the insurance bets. If the hole card is 10-point card, the dealer has blackjack, the card is revealed, and insurance bets are paid. If the hole card is not a 10-point card, the insurance bets are lost, but the card is not revealed.

In the unusual case that the dealer shows an ace and the player shows blackjack (21 in two cards), the player will be offered "even money" instead of the insurance bet. If the player accepts the even money offer, their hand is resolved at 1:1 immediately, without examining the dealer's hole card or playing out the hand. If the player declines even money, they can still bet or decline insurance. Checking the odds carefully, there is a 4/13 (30.7%) chance of the dealer having 21, but insurance is paid as if the odds were 1/3 (33.3%). Since the player knows they have 21, there is a 4/13 probability of a push plus winning the insurance bet (both player and dealer have 21) and a 9/13 probability of winning at 3:2, but losing the insurance bet (effectively a push).

**Split Hands.** When dealt two cards of the same rank, the player can split the cards to create two hands. This requires an additional bet on the new hand. The dealer will deal an additional card to each new hand, and the hands are played independently. Generally, the typical scenario described above applies to each of these hands. The general rule of thumb is to always split aces and eights.

The ideal situation is to split aces, and get dealt a 10-point card on each ace. Both hands pay 3:2. A more common situation is to have a low card (from 2 to 7) paired up with the ace, leading to soft 13 through soft 18. Depending on the dealer's up card, these are opportunities to double down, possibly increasing the bet to 4 times the original amount.

Some casinos restrict doubling down on the split hands. In rare cases, one or more of the new cards will match the original pair, possibly allowing further splits. Some casinos restrict this, only allowing a single split. Other casinos prevent resplitting only in the case of aces.

Note that the player's election to split hands is given after any offer and resolution of insurance bets.

## Available Bets and Choices

Unlike Roulette and Craps, Blackjack has only a few available bets. Generally, the following choices all involve accepting an offer by creating an additional bet.

- **Ante.** This bet is mandatory to play. It must be within the table limits.
- **Insurance.** This bet is offered only when the the dealer shows an ace. The amount must be half the ante. Note that the even money offer is an option for resolution of the ante instead of an insurance bet. It is sometimes described as a separate kind of bet, but this doesn't seem accurate.
- **Split.** This can be thought of as a bet that is offered only when the the player's hand has two cards are of equal rank. Or this can be thought of as a playing option, akin to hitting or standing. The amount of the bet must match the original ante.
- **Double.** This can be thought of as a bet that is offered instead of a taking an ordinary hit. Some casions only offer this when the the player's hand has two cards. Or this can be thought of as a playing option, akin to hitting or standing. The amount of the bet must match the original ante.

Blackjack also offers the player some choices that don't involve creating additional bets. In the casino these are shown through gestures that can be seen clearly by dealers and other casino staff.

- **Even Money.** This resolution of insurance is offered only when the the dealer shows an ace and the player shows 21 in two cards. It is offered instead of an insurance bet. If accepted, the hand is resolved. If declined, the insurance offer can then be accepted or declined.
- **Hit.** The player is offered the opporutunity to take another card when their total is less than 21. If they decline the hit, they are standing pat. In casinos that allow a double down on any number of cards, the player has three choices: hit, double down or stand.

Play begins with a sequence of offers which can be accepted or declined: insurance, even money resolution of insurance, and splitting a hand. After these offers, the player must select between the three remaining choices (hit, double or stand) for each of their hands with a total less than 21.

In Roulette, there are no additional offers for the player to accept or decline. In Craps, we ignored the only offer made to a player. See Optional Working Bets for details on this rule. Adding this interaction to Craps would require defining an additional method for `CrapsPlayer` to accept or decline an offer. We would also have the `CrapsGame` interrogate the `Table` for the presence of come point odds bets, make the offer to the player, and then activate or deactivate the bet for the next throw only. This level of interaction was a nuance we elected to ignore at that time.

## Betting Strategies

Because of the complexity of Blackjack, the strategies for play focus on the cards themselves, not on the bets. Some players use a single fixed bet amount. Some players will attempt to count cards, in an effort to determine the approximate distribution of cards in the deck, and vary their play or bets accordingly. The casinos actively discourage counting in a number of ways. The most common way is to shuffle 5 decks of cards together, and only deal the first 156 or so of the available 260 cards. Additionally, they will ask people to leave who are obviously counting.

The player's responses to the various offers are what defines the playing strategy in Blackjack. The information available to the player is their hand (or hands), and the dealer's up card. Therefore, all of the strategies for play decompose to a matrix showing the player's total vs. dealer's up card and a recommendation for which offers to accept or decline.

Most players will decline the insurance offer, except when they hold a 21. In that rare case the even money offer should be declined, since the expected value analysis of the result shows a slightly better payout by competing against the dealer.

The decision matrix has two parts: accepting or rejecting the split offer, and choosing among hit, stand or double down. You can buy cards in casino gift-shops that summarize a playing strategy in a single, colorful matrix with a letter code for split, hit, double and stand. Note that each decision to hit results in a new card, changing the situation used for decision-making. This makes the strategy an interesting, stateful algorithm.

A player could easily add the betting strategies we've already defined to their Blackjack play strategies. A player could, for example, use the Martingale system to double their bets on each hand which is a loss, and reset their betting total on each hand which is a win. Indeed, our current design permits this, since we disentangled the betting strategies from the individual games in Chapter 33, *Roll-Counting Player*.

# Chapter 36. Blackjack Solution Overview

**Table of Contents**

We will present a survey of the new classes gleaned from the general problem statement in Problem Statement as well as the problem details in Blackjack Details. This survey is drawn from a quick overview of the key nouns in these sections. We will not review those nouns already examined for Craps and Roulette.

## Preliminary Survey of Classes

In reading the background information and the problem statement, we noticed a number of nouns that seemed to be new to the game of Blackjack.

Card
Deck
Point Value
Hand

Number Card
Face Card
Offer
Insurance
Split
Double
Hit
Stand
Player
Game

The following table summarizes some of the new classes and responsibilities that we can identify from the problem statement. This is not the complete list of classes we need to build. As we work through the exercises, we'll discover additional classes and rework some of these classes more than once.

We also have a legacy of classes available from the Roulette and Craps solutions. We would like to build on this infrastructure as much as possible.

**Preliminary Class Structure**

| Class | Responsibilities | Collaborations |
|---|---|---|
| `Card`, with three apparent subclasses: `NumberCard`, `FaceCard` and `Ace` | A standard playing card with a rank and a suit. Also has a *point value* from 1 to 11. Aces have point values that depend on the `Hand`. | Collected in a `Deck`; collected into `Hands` for each `Player`; collected into a `Hand` for the dealer; added to by `Game`. |
| `Deck` | A complete set of 52 standard `Cards`. | Used by the `Game` to contain `Cards`. |
| `Hand` | A collection of `Cards` with one or two point values: a hard value (an ace counts as 1) and a soft value (an ace counts as 11). The house will reveal one `Card` to the player. | A `Player` may have 1 or more `Hands`; a `Hand` has 2 or more `Cards`. The `Game` adds `Cards` to the `Hand`. The `Game` checks the number of cards, the point totals and the ranks of the cards to offer different bets. The `Game` compares the point totals to resolve bets. |
| `Player` | Places the initial ante `Bets`, updates the stake with amounts won and lost. Accepts or declines offered additional bets, including insurance, and split. Accepts or declines offered resolution, including even money. Chooses among hit, double and stand options. | Uses `Table`, and one or more `Hands`. Examines the dealer's `Hand`. Used by game to respond to betting offers. Used by `Game` to record wins and losses. |
| `Game` | Runs the game: offers bets to `Player`, deals the `Cards` from the `Deck` to `Hands`, updates the state of the game, collects losing bets, pays winning | Uses `Deck`, `Table`, `Outcome`, `Player` |

| | | |
|---|---|---|
| Game | bets. Splits `Hands`. Responds to player choices of hit, double and stand. This encapsulates the basic sequence of play into a single class. | Uses `Deck`, `Table`, `Outcome`, `Player`. |

## A Walkthrough

The unique, new feature of Blackjack is the more sophisticated collaboration between the game and the player. This interaction involves a number of offers for various bets, and bet resolution. Additionally, it includes offers to double, hit or stand. We'll examine parts of a typical sequence of play to assure ourselves that we have all of the necessary collaborations and responsibilities.

A good way to structure this task is to do a CRC walkthrough. For more information on this technique see A Walkthrough of Roulette. We'll present the overall sequence of play, and leave it to the student to manage the CRC walkthrough.

**Procedure 36.1. Typical Blackjack Game**

1. **Place Bets**

   The Game will ask the player to place a bet. If the player doesn't place a bet, the session is over.

2. **Create Hands**

   The Game will deal two cards to the Player's initial Hand.

   The Game will create an initial hand of two cards for the dealer. One of the cards is the up card, and is visible to the player.

3. **Insurance?**

   The Game gets the Dealer's Hand's up card. If it is an Ace, then insurance processing is perforemed.

   a. **Offer Even Money**

      The Game examines the Player's hand for two cards totalling a soft 21, blackjack. If so, the Game offers the Even Money resolution to the Player. If the player accepts, the entire game is resolved at this point. The ante is paid at even money; there is no insurance bet.

   b. **Offer Insurance**

      The Game offers insurance to the Player, who can accept by creating a bet. For players with blackjack, this is a second offer after even money is declined. If the player declines, there are no further insurance considerations.

   c. **Examine Hole Card**

      The Game examines the Dealer's Hand's hold card. If is is a 10-point value, the insurance bet is resolved as a winner, the ante is resolved as a loser, and for this player, the game is over.

Otherwise the insurance is resolved as a loser, the hole card is not revealed, and play will continue. Note that in a casino with multiple players, it is possible for a player declining insurance to continue to play with the dealer's hole card revealed. For casinos that offer “early surrender” this is the time to surrender.

4. **Split?**

   The Game examines the Player's Hand to see if the two cards are of equal rank. If so, it offers a split. The player accepts by creating an additional Bet. The original hand is removed; The Game splits the two original Cards then deals two additional Cards to create two new Hands.

   Some casinos prevent further splitting, others allow continued splitting of the resulting hands.

5. **Play Out Player Hands**

   The following are done to play out each of the Player's Hands.

   a. **Bust? Double? Hit? Stand?**

      While the given Hand is under 21 points, the Game must extend three kinds of offers to the Player. If the Player accepts a Hit, the hand gets another card and this process repeats.

      If the Player accepts Double Down, the player must create an additional bet, and the hand gets one more card and play is done. If the Player Stands Pat, the play is done. If the hand is 21 points or over, play is done.

   b. **Resolve Bust.**

      The Game must examine each Hand; if it is over 21, the Hand is resolved as a loser.

6. **Play Out Dealer Hand**

   The Game then examines the Dealer Hand and deals Cards on a point value of 16 or less, and stops dealing Cards cards on point value of 17 or more.

7. **Dealer Bust?**

   The Game then examines the Dealer Hand to see if it is over 21. If so, the player's bets are resolved as winners. Player Hands with two cards totalling 21 (“blackjack”) are paid 3:2, all other hands are paid 1:1.

8. **Compare Hands**

   For each hand still valid, the Game compares the Player's Hand point value against the Dealer's Hand point value. Higher point value wins. In the case of a tie, it is a push and the bet is returned.

   When the Player wins, a winning hand with two cards totalling 21 (“blackjack”) is paid 3:2, any other winning hand is paid 1:1.

## Questions and Answers

**Q:** Will we really need both `Deck` and the multiple deck `Shoe`? Wouldn't it be simpler to combine this functionality into a single class?

**A:** There are two separate responsibilities here. The deck owns the basic responsibility to build the 52 cards. The shoe, on the other hand, owns the responsibility to deal cards to hands.

We want to be able to simulate games with 1 to 8 decks. A single deck game can simply deal directly from the deck. In a multi-deck game, all of the decks are shuffled together and loaded into a *shoe* for dealing. The difference between one deck and a five-deck shoe is that the shoe can produce 20 kings in a row. While rare, our simulation does need to cover situations like this.

Also, we may want to build a slightly different shoe that simulates the continuous shuffling machine that some casinos use. In this case, each hand is reshuffled back into the shoe, preventing any attempt at card counting. We don't want to disturb the basic, common deck when introducing this additional feature.

**Q:** Won't all those player interactions break our design?

**A:** That's unlikely. All of that player interaction is in addition to the `placeBets` interface. Since we've separated the core features of all players from the game-specific features, we can add a subclass to player that will be handle the Blackjack interaction. This new player subclass will have a number of additional methods to handle insurance, even money, split and the regular play questions of hit, double and stand.

In parallel, we've separated the core features of all games from the unique features for a specific game. We can now add a subclass for Blackjack which adds a number of methods to offer insurance, even money, split and the regular play questions of hit, double and stand to the Blackjack player.

**Q:** I can't find an Outcome in Blackjack. Is it the Ante? If so, the odds vary based on the player's Hand, but that doesn't seem to be a RandomEvent.

**A:** Good point. We'll examine this in detail in the exercises. Clearly, the bets are placed on the Ante and Insurance as the two core `Outcomes` in Blackjack. The Insurance outcome (really a “dealer has blackjack” outcome) is fixed at 2:1. The ante payoff depends on a complex condition of the hand: for a soft 21, or blackjack, it pays 3:2; otherwise it pays 1:1. This will lead to a new subclass of `Outcome` that collaborates with the hand to determine the payout to use.

The “even money” is offered before ordinary insurance to a player with blackjack. It, however, pays even money on the ante, and doesn't create a new bet; in this respect it could be thought of as a change in the outcome on which the ante bet is created. Accepting the even money offer is a little bit like moving the ante to a “even money for dealer blackjack” outcome, which has 1:1 odds instead of 3:2 odds. Further, this special outcome is resolved before the dealer peeks at their hole card. Perhaps this is a special best resolution procedure, not a proper instance of `Outcome`.

# Chapter 37. Card, Deck and Shoe Classes

**Table of Contents**

This chapter introduces a number of simple classes. When exploring Roulette, we introduced classes very slowly. In this chapter, we are introducing the class hierarchy for cards, the deck of cards and the shoe, used by the dealer to create hands. The next chapter will introduce the hand, and the problems of scoring the value of the hand.

## Overview

**Card.** The standard playing card has two attributes: a rank (Ace, 2 through 10, Jack, Queen, or King) and a suit (Clubs, Diamonds, Hearts or Spades). The set of all 52 combinations comprises a full deck. Additionally, in Blackjack, a card has a point value, which is a number from 1 to 11, and is based on the rank. In the case of an Ace, it is also based on the hand in which the card is evaluated. This collaboration with a hand complicates the responsibilities for a single card. However, the basic set of responsibilities of the `Card` class include keeping the rank, suit and point value of a single standard playing card.

The issue of suit requires some care. In the game of Blackjack, suits don't matter. Indeed, for the purposes of simulation, we could simply discard the notion of suit. However, for the purposes of making a reasonably complete model of real-world objects, it makes sense to implement the suit of a card, even if we do nothing with it.

We'd like to provide symbolic variable names for the suits. In Java we'll use static final variables to define the suits. In Python we'll use class variables. This will give us four named constants for each of the suits, something that tends to make the software easier to read. Similarly, we'll provide named constants for the three face cards and the ace.

We have three different rules for establishing the point value of a card. This is a big hint that we have three subclasses. One subclass includes the Aces, which are either 1 or 11 points. Another subclass includes the number cards from 2 to 10, where the rank is the point value. Finally, the third subclass includes the face cards, where the point value is fixed at 10. These three subclasses implement slightly different versions of a method to return the point value of the card. For more discussion on this, see Why are there three subclasses of Card? Isn't it simpler to have one class and use an if-statement to sort out the point values. FAQ for more discussion.

The problem of determining the value of aces is something we will have to defer until after we create the hand class. First, we'll implement the basic card, then we'll develop the hand, and decide how the hand computes its number of points from the cards. We do note that the terminology used gives us some hint as to how to structure our design. Players refer to a *soft* total and a *hard* total. An A-6 hand is called a soft 17, and a hard 7. A soft hand has some flexibility in how it is played. If you hit a soft 17, and get a face card (for example, a Jack), you now have an A-J-6, totalling hard 17. Considering this, we can provide two point-value functions for each rank, a hard value and a soft value. For all but aces, the two values are the same. For aces, the two values are different. This would allow a hand to compute a hard total and a soft total for the hand as a whole. While this design does have some potential problems in dealing with multiple aces in a single hand, we'll let it stand until we have more design in place.

**Deck.** A deck of cards has responsibility for shuffling and dealing the various cards. Additionally, it should constuct the complete set of 52 cards. We note that shuffling uses a random number generator, but a deck isn't the same kind of random event factory that a Wheel or pair of Dice is. In the case of Wheel and Dice, the random events were based on random selection with replacement: an individual event can be regenerated any number of times. In the case of a deck, however, once a card has been dealt, it will not show up until the deck is shuffled.

In Roulette and Craps, the odds depended on a `RandomEvent`: either the `Bin` or `Throw`. In Blackjack, the ante's win amount depends on the player's entire hand. This means that being dealt an individual card isn't the same kind of thing that a throw of the dice is; rather it suggests that the dealer's shoe is the random event factory, and the entire hand is the random event created by dealing cards. Continuing this line of thought, an `Outcome`'s win amount could depend on a `RandomEvent`, if we consider the entire hand to be the random event.

Considering an entire hand to be a single random event is skating on pretty thin ice, so we won't force-fit a `Deck` into the random event factory part of our framework. Instead, we will let `Deck` stand alone. We'll design a simple initialization for a deck that constructs the 52 cards. Beyond that, the notions of shuffling and dealing can be assigned to the shoe.

Since a `Deck` is a container, we have to examine the available collection classes to determine which concrete class we need. Interestingly, we only need two features of `Collection`: the `add` method and the `iterator`. These methods are implemented for all of the variations of `Set` and `List`. The only collection we can disregard is `HashSet` as that will use more storage than necessary.

**Shoe.** The dealer's shoe is where `Cards` are shuffled and dealt to create individual hands. A shoe will be built from some number of `Decks`. More properly, the shoe will contain the `Cards` from those `Decks`. The `Deck` objects aren't really used for much more than constructing batches of individual `Card` objects. The `Shoe` responsibilities include proper initialization using a given number of decks, periodic shuffling and proper dealing.

In a casino, the shuffling involves a ritual of spreading the cards on the table and stirring them around thouroughly, then stacking them back into the shoe. The top-most card is extracted, shown to the players, discarded, and a marker card is cut into the shoe at least two decks from the end, leaving about 100 cards unplayable after the marker. While most of the ritual does not require careful modeling, the presence of undealt cards at the end of the shoe is important as a way to defeat card-counting strategies.

Since a `Shoe` is a container, we have to examine the available collection classes to determine which concrete class we need. Interestingly, we only need two features of `Collection`: the `addAll` method to put another deck into the shoe and the `iterator`. These methods are implemented for all of the variations of `List`. We will have to disregard the various `Set` implementations because they impose their own unique orders on the elements, different from our shuffled order.

The simplest shuffling algorithm iterates through all of the `Cards` in the `Shoes` collection, and exchanges that `Card` with the card in a randomly-selection position. In order to move `Cards` around freely within the structure, an `ArrayList` or `Vector` could be used. See Is that the best shuffling algorithm Won't it sometimes move a card twice? Won't it sometimes put a card back into the original spot? for more discussion on shuffling.

## Questions and Answers

Q: Why are there three subclasses of Card? Isn't it simpler to have one class and use an if-statement to sort out the point values.
Q: Is that the best shuffling algorithm Won't it sometimes move a card twice? Won't it sometimes put a card back into the original spot?

**Q:** Why are there three subclasses of Card? Isn't it simpler to have one class and use an if-statement to sort out the point values.

**A:** Primarily, there are three classes because they have different behaviors. Merging them into a single class and sorting out the behaviors with an if-statement is often a problem.

First, and most important, if-statements add complexity. The question “wouldn't it be simpler to use an if-statement” is a kind of oxymoron.

Second, and almost as important, if-statements dilute responsibility assignments. Combining all three subclasses into one puts three slightly different responsibilities into one place, making it more difficult to debug problems. Further, we could wind up repeating or other reusing the if-statement in inappropriate ways. If we create separate subclasses, the clear separation of responsibility becomes a matter of definition, not a matter of following a complex thread of programming logic.

Third, if-statements limit growth, adaptation and change. If we have a modification to the rules, for example, making 1-eyed Jacks wild, we would prefer to simply introduce another subclass. We find that chasing down one or more related if-statements to assure ourselves that we are correctly handling the new subtlety rapidly gets out of hand.

**Q:** Is that the best shuffling algorithm Won't it sometimes move a card twice? Won't it sometimes put a card back into the original spot?

**A:** Yes, it may move some cards twice and it may leave a card in position. This is part of random behavior. This algorithm touches every card, swapping it with a randomly selected card. We are assured that every card was put into a random position. Sometimes a card will have been moved more than once, but the minimum criteria is that every card has been moved.

While a shuffling algorithm that models the real world is tempting, this adds complexity for no actual improvement in the randomization. A popular technique in the real world is to cut the deck in half and then riffle the cards into a single pile. If done with the kind of perfection that software provides (cutting the deck exactly in half and exactly alternating the cards) this shuffle leads to a perfectly predictable cycle of orders. What makes this shuffle work in the real world is the random inaccuracies in cutting and riffling. We don't see any value in modeling these physical phenomenon.

A similar analysis holds for the kind of shuffle done in the casino. In essence, they do a shallow copy if the original `List` object, and then rebuild the shoe's `List` by picking cards at random from the copy. This produces a result that is statistically indistinguishable from our algorithm, which uses an element-by-element swap.

One fruitless side-track is using the seemingly-random hash code values of the `Card` objects. This only puts the cards into a single fixed, but arbitrary order. An interesting alternative is to generate a random index for each `Card` and then sort by this index or assemble a `SortedSet`. We note that sorting is O(*n*)log(*n*), where our algorithm is O(*n*), running much faster than any sort.

## Design

This section contains a number of individual class designs. It has the `Card` class hierarchy. Additionally, it has `Deck` and `Shoe`. All of these classes are quite simple.

### Card superclass

`Card` defines a basic playing card. It has a rank, a suit, a hard point value and a soft point value. The point value methods are defined for the number cards from 2 to 10. Two subclasses handle face cards, where the point values are both 10, and aces, where the soft point value is 1, and the hard point value is 11.

This class also defines names for the suits (Clubs, Diamonds, Hearts and Spades) and face cards (Jack, Queen and King).

#### Fields

In Java, named constants are marked as static and final. Being static, they are part of the class definition and belong to the class, making it possible to refer to `Cards.Spades`. Being final, they cannot be changed once they are initialized.

In Python, these kinds of named constants are declared within the class, not within the initialization method function. They cannot easily be made into unchangable constants.

**Example 37.1. Python Constant Declaration**

```
class Card:
    Clubs, Diamonds, Hearts, Spades = 0, 1, 2, 3
    Jack, Queen, King = 11, 12, 13
    def __init__( self, rank, suit ):
        self.rank= rank
        self.suit= suit

oneEyedJack= Card( Card.Jack, Card.Hearts )
```

- `static final int Clubs = 0;`
- `static final int Diamonds = 1;`
- `static final int Hearts = 2;`
- `static final int Spades = 3;`
- `static final int Ace = 1;`
- `static final int Jack = 11;`
- `static final int Queen = 12;`
- `static final int King = 13;`
- `int rank ;`

  The rank of the card. This is a number from 1 (Ace) to 13 (King).

- `int suit ;`

  The suit of the card. This is a number code for Clubs, Diamonds, Hearts or Spades.

### Constructors

-
  ```
  Card(int rank,
        int suit);
  ```

  Initializes the attributes of this `Card`.

### Methods

- `public int getRank();`

  Returns the rank of this card.

- `public int softValue();`

  Returns the soft value of this card. The superclass simply returns the rank. Subclasses can override this. Face cards will return 10, Aces will return 11.

- `public int hardValue();`

  Returns the hard value of this card. The superclass simply returns the rank. Subclasses can override this. Face cards will return 10, Aces will return 1.

- `public String toString();`

  Returns a short String displaying the rank and suit of this card.

## FaceCard class

`FaceCard` is a `Card` with a point value of 10. This defines jack, queens and kings.

### Methods

- `public int softValue();`

  Returns the soft value of this card, 10.

- `public int hardValue();`

  Returns the hard value of this card, 10.

- `public String toString();`

  Returns a short String displaying the rank and suit of this card. The ranks are translated to single letters: 11 to 'J', 12 to 'Q' and 13 to 'K'.

## AceCard class

`AceCard` is a `Card` with a soft point value of 11 and a hard point value of 1. This defínces Aces.

### Methods

- `public int softValue();`

  Returns the soft value of this card, 11.

- `public int hardValue();`

  Returns the hard value of this card, 1.

- `public String toString();`

  Returns a short String displaying the rank and suit of this card. The rank is always 'A'.

## Deck class

`Deck` defines the standard deck of 52 cards. It both constructs the deck and acts as a container for one instance of a deck.

### Fields

- `Collection cards ;`

  The collection of individual cards. The specific type of collection could be any of the Set or List implementation classes.

### Constructors

- `Deck();`

  Creates the Collection, `cards`, and then creates the 52 cards. A simple nest pair of loops to iterate through the suits and ranks will work nicely for this.

  **Procedure 37.1. A Full Deck**

  - For all four suits:

    a. Create the AceCard of this suit and a rank of 1; add to the `cards`

    b. For ranks 2 to 10:

       i. Create a Card of this suit and rank; add to the `cards`

    c. For ranks 11 to 13:

       i. Create a FaceCard of this suit and rank; add to the `cards`

### Methods

- `public Collection getCards();`

  Returns the collection of cards in `cards`.

## Shoe class

`Shoe` defines the dealer's shoe, which contains from 1 to 8 decks of cards. For one deck shoes, one card is reserved as undealable. For multiple deck shoes from 1 to 3 decks can be left undealt. The exact number is selected at random within 6 cards of the expected number of decks.

### Fields

- `List cards ;`

  The entire collection of cards from 1 to 8 decks.

- `Iterator deal ;`

  The iterator used to pick the next card from the shoe.

- `int stopDeal ;`

  The number of decks to be left undealt in the shoe.

### Constructors

-
  ```
  Shoe(int decks,
       int stopDeal);
  ```

  Creates a random number generator from `java.util.Random`, and uses the other constructor method with this generator.

-
  ```
  Shoe(int decks,
       int stopDeal,
       Random rng);
  ```

  Initializes the Shoe by creating the required number of decks and building the `cards` `List`. This saves the *`stopDeal`* value, which is the number of decks left in the shoe. Typically, this is two, and between 98 and 110 cards are left in the shoe. This also saves the random number generator used to shuffle.

  To facilitate testing, this initializes the iterator to the first card in the `List`. This will produce cards in a fixed order.

### Methods

-
  ```
  public void shuffle();
  ```

  Shuffles the shoe by swapping every element in the `cards` `List` with a random element. Creates an `Iterator`, `deal`. It uses the iterator's `next` to advance past the first card.

  If the `stopDeal` is non-zero, do the following to exclude several decks from the deal. First, create a random number, `offset` between -6 and 6; this is done by generating a number between 0 and 12 and then subtracting 6. Use a loop to go from 0 to 52*`stopDeal+offset`; the body of the loop calls the `deal` iterator's `next` method to skip past those cards in the shoe.

-
  ```
  public Card next()
      throws NoSuchElementException;
  ```

  Returns the next `Card` from the `deal` iterator.

-
  ```
  public boolean hasNext();
  ```

  Returns the value from the `hasNext` method of the `deal` iterator.

## Deliverables

There are 10 deliverables for this exercise.

- The three classes of the `Card` class hierarchy, including `FaceCard` and `AceCard`.
- A class which performs a unit tests of the `Card` class hierarchy. The unit test should create several instances of `Card`, `FaceCard` and `AceCard`.
- The `Deck` class.

- A class which performs a unit test of the `Deck` class. This simply creates a `Deck` object and confirms the total number of cards. A thorough test would also check some individual `Card` objects in the cards collection.
- The `Shoe` class.
- A class which performs a unit test of the `Shoe` class. This simply creates a `Shoe` object and confirms that it deals cards. In order to test the `shuffle` method, you will need to construct the `Shoe` with a random number generator that has a fixed seed and produces cards in a known sequence.

# Chapter 38. Hand and Outcome Classes

**Table of Contents**

This chapter introduces the hand, and the problems of scoring the value of the hand. It also introduces a subclass of `Outcome` that can handle the more complex evaluation rules for Blackjack.

## Overview

The hand of cards is both a container for cards, but is also one dimension of the current state of the player's playing strategy. A player may have multiple hands, and the hands are resolved independently. Responsibilities include holding the cards, producing a hard and soft point total.

**What Class is Hand?** Our first design problem is to determine what class of object the hand is. The hand, as a whole, may be a kind of `Outcome`, since the win amount depends on the structure of the hand. A two-card hand totalling soft 21 is called blackjack and has an outcome that pays 3:2, all other winning outcomes pay 1:1, or are a push (effectively 0:1).

However, a hand is not precisely a single `Outcome` contained in a `RandomEvent`, which is generated by a `RandomEventFactory`. The difference is that a hand evolves into a particular outcome based on player actions to add cards, or based on the dealer's actions to add cards to their `Hand`. As we look more closely, the `Outcome` is the result of a comparison between two `Hands`; and it is done at several points in the game.

We'll enumerate all of the individual `Outcomes` that are part of the game.

1. “Insurance” at 2:1. This is a winner when the dealer's hand is blackjack; and the “Ante” bet will be a loser. It is only offered when the up card is an Ace. This is a loser when the dealer's hand is not blackjack, and the Ante bet is unresolved.

2. “Even Money” at 1:1. This is offered in the rare case of the player's hand is blackjack and the dealer's up card being an Ace. If accepted, it can be looked at as a switch of the Ante bet to an “Even Money” outcome, which is then resolved as a winner.

3. “Ante” at 3:2. This payout occurs when the player's hand is blackjack.

4. “Ante” at 1:1. This payout occurs when the player's hand is less than or equal to 21 and the dealer's hand goes over 21. This payout also occurs when the player's hand is less than or equal to 21 and greater than the dealer's hand.

5. “Ante” at 0:1, a push. This payout occurs when the player's hand is less than or equal to 21 and equal to the dealer's hand.

6. “Ante”. This outcome is a loser as soon as the player's hand goes over 21. It is also a loser when the player's hand is less than or equal to 21 and less than the dealer's hand.

In Craps, we identified the Field and Horn `Outcomes` which had winning amounts that depended on the specific `Throw`. See the section called “Overview”, for more information. Additionally, we compared `Bets` against the `Outcomes` as part of the transition from one `GameState` to another. see the section called “Overview”, for more information.

In Blackjack, the `winAmount` of an `Outcome` needs to examine the player's `Hand` to determine the payout odds. Changes to the state of the game depend on the values of both hands, as well as the visible up card in the dealer's hand. In these respects, a `Hand` appears to be a kind of `RandomEvent`, akin to a `Throw`.

While a `Hand` could be treated as a subclass of `RandomEvent`, it jars our sensibilities. A `Hand` is built up from a number of `Cards`. One could rationalize this calling a `Hand` an “event” by claiming that the act of shuffling is the factory that creates a random event -- the order of cards in the `Shoe` -- and that event is then revealed one card at a time.

This is point where some Java programmers feel the urge to use the interface mechanism and declare that a `Hand` shares a common interface with a `RandomEvent`, but is really a different kind of thing. In order to create the interface definition, we would extract the set of features common to `Throw` and `Hand` that are used by an `Outcome` to determine the win amount. In the case of the `Throw` it's the total of the two dice. In the case of the `Hand` it's the soft total and the number of cards. Sadly, there isn't a lot of common data here. This makes it unclear that introducing an interface simplifies anything about this design.

When we can't find common data, it often means that we can still find a common method. In this case, we might be able to create an interface to `Outcome` that allows a `Throw` or `Hand` to adjust the payout odds. This takes responsibility away from `Outcome`. While technically possible, it still doesn't simplify anything.

Our first design decision, then is to leave `Hand` as a stand-alone class, separate from `Throw`. This will allow us to create a subclass of `Outcome` for the Ante bet that checks the player's `Hand` to determine the win amount. This will tightly couple our `AnteOutcome` with `Hand`. We'll return to that part of the design below in Outcome Specialization.

**Point Value Calculation.** Our second design problem is to calculate the point value of the hand. We note that only one ace participates in the hard total vs. soft total decision-making. If two aces contribute soft values, the hand is at least 22 points. Therefore, we need to identify only one ace to use the soft value of 11, all other cards will contribute their hard values to the hand's total value.

This observation makes the process of totaling the points in a hand stateful. Normally, the hand simply computes the hard total of all cards. If the hand has one or more aces, it uses a variant algorithm that computes the hard total with all but one ace, and then determines wether the last ace should contribute the hard or soft value to keep the hand from going bust.

Our second design decision is to identify one of the aces for special treatment when computing the point value for a hand. We have a number of ways of singling out this card. The easiest is to have an additional field in the class which is set as a reference to an ace. This could be done by examining each card as it is added to the hand for a card with distinct hard and soft values; or we could check the set of cards when asked to compute the value of the hand.

We note that this design is perilously close to breaking the cardinal rule of polymorphism. In order to locate the Aces in our hand, we almost need to ask what subclass of `Card` the object is. However, we aren't specifically interested in knowing the subclass of the `Card` object, but rather knowing the value of a property of the `Card` object. The property we care about is the difference between the hard and soft value of the `Card`. Because this value is a property of each individual object -- not the name of the object's class -- we have not broken the essential symmetry of polymorphism: we will treat all subclasses alike.

### Important

To continue this rant, we note that many programmers conflate properties of objects and the class of the object, breaking the symmetry of polymorphism. We'll repeat this important point by referring to Soapbox On Polymorphism.

**Outcome Specialization.** As a final design decision, we need to create a subclass of `Outcome` to handle the variable odds for the “Ante” bet. We don't need a subclass for the “Insurance” or “Even Money”, because the base `Outcome` does everything we need.

The notable complication here is that there are three different odds. If the player's hand beats the dealer's hand and is blackjack, the odds are 3:2. If the player's hand beats the dealer's hand, but is not blackjack, the odds are 1:1. If the player's hand equals the dealer's hand, the result is a push, effectively 0:1 odds.

We'll need to define an `OutcomeAnte` class that has a version of `winAmount` based on a player's `Hand` and the dealer's `Hand`. This will be used if the player's hand is not bust and the player's hand is a winner. The definition of the player being a winner is that the dealer is bust or the player's point total is greater than or equal to the dealer's.

## Design

### Hand Class

`Hand` contains a collection of individual `Card`s, and determines an appropriate total point value for the hand.

#### Fields

- `List theCards = null;`

  Holds the individiual `Card`s of this hand.

- `Card theAce = null;`

  Holds a reference to one card with different hardValue and softValue. Typically, this will be first ace we are dealt. However, there may be a game variation in which cards other than aces present varying point totals.

### Constructors

- `Hand();`

  Creates an empty hand. The `theCards` variable is initialized to an empty LinkedList, and the `theAce` is reset to `null`.

- `Hand(Card aCard);`

  Uses the default constructor to create an empty hand. Then uses the `add` method to add this card to the hand.

### Methods

- `public void add(Card aCard);`

  Add this card to the `theCards` list. If `theAce` is `null` and *`aCard`* has a different point total for `hardValue` and `softValue`, then save this card in `theAce`.

- `public int value();`

  Computes the point value of this hand. First, it sums the hard value of each card. If `theAce` is `null`, then there is no ace, and this is the final total that is returned.

  When there is an ace, we'll need to compute the soft total for the hand. The best way to to this is to use `hardTotal` - `theAce.hardValue()` + `theAce.softValue()`. Typically, the soft total is 10 more than the hard total, but the responsibility for providing the value belongs with `Card`, not this class. If the hand's soft total is 21 or less, this is returned. Otherwise, the hard total is returned.

- `public int size();`

  Returns the number of cards in the hand, the size of the `List`.

- `public boolean blackjack();`

  Returns true if this hand has a size of two and a value of 21.

- `public boolean busted();`

  Returns true if this hand a value of over 21.

- `public Iterator iterator();`

  Returns an iterator over the cards of the `List`.

- `public String toString();`

  Displays the content of the hand as a String with all of the card names.

## OutcomeAnte Design

`OutcomeAnte` contains a single outcome for the blackjack ante bet that has a number of different odds, and the odds used depend on the `Hand`.

### Methods

- `double winAmount(int amount);`

  In Python, this method should raise the `NotImplementedException`. In Java, this method can throw the `NoSuchMethedException`. This method should not be called for this kind of outcome; any attempt to do so is a serious design error.

-
  ```
  double winAmount(int amount,
                   Hand event);
  ```

  Checks the `Hand` to locate the correct odds. Blackjack uses 3:2, other hands use 1:1. Returns the product of the appropriate odds numerator by the given amount, divided by the odds denominator.

-
  ```
  double winAmount(int amount,
                   Hand event,
                   int dealerPoints);
  ```

  Checks the `Hand` to locate the correct odds. If the *`event`* point value is greater than the *`dealerPoints`*, odds are 1:1; return the product of the appropriate odds numerator by the given amount, divided by the odds denominator. If the point values are equal this is a push, simply return the bet *`amount`*.

- An easy-to-read String output method should return a String representation of the name and the odds. A form that looks like `Ante (3:2)` works nicely.

## Deliverables

There are 4 deliverables for this exercise.

- The `Hand` class.

- A class which performs a unit tests of the `Hand` class. The unit test should create several instances of `Card`, `FaceCard` and `AceCard`, and add these to instances of `Hand`, to create various point totals.
- The `OutcomeAnte` class.
- A class which performs a unit tests of the `OutcomeAnte` class. The unit test should create several instances of `Card`, `FaceCard` and `AceCard`, and use these to create several different `Hands`. These `Hands` can then be given to an `AnteOutcome` instance to check the determination of win amounts.

# Chapter 39. Blackjack Table Class

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The bets in Blackjack are associated with a hand. This will lead us to create a subclass of table to handle this complexity. In order to manage the relationships between hand and bet, we'll rework hand, also.

## Overview

When we look at the game of Blackjack, we note that a player's `Hand` can be split. In some casinos, resplits are allowed, leading to the possibility of 3 or more `Hands`. Each individual `Hand` has a separate ante `Bet` and seperate resolution. This is different from the way bets are currently managed for Roulette and Craps.

One solution is to create a subclass of `Table` with resposibilities to keep track of bets by `Player` and individual `Hand`. This would make the `Hand` a potential key into a Map that associated a `Hand` with a `Bet`. However, `Hands` change state, making them poor choices for keys to a Map.

Another solution is to simply put a reference to a `Hand` into the `Bet`. Similarly, we could put a reference to the Ante `Bet` in the `Hand`. In this way, as each `Hand` is resolved, the relevant `Bet` can be paid or lost. We'll design `Hand` to contain the associated ante `Bet`. This will work in conjuction with `OutcomeAnte` which has the associated `Hand`.

While most `Bets` are associated with a specific `Hand`, the insurance `Bet` is always resolved before another hand is created. There doesn't seem to be an essential association between the initial `Hand` and the insurance `Bet`. We can treat insurance as a `Bet` that follows the model established for Craps and Roulette.

Currently, `Bets` are placed on the `Table`. If we create a subclass named `BlackjackTable` that uses a `Hand` when creating a `Bet`, we can have this method do both tasks: it can attach the `Bet` to the `Hand`, and it can save the `Bet` on the `Table`.

# Design

## BlackjackTable Class

`BlackjackTable` is a `Table` that handles the additional association between `Bets` and specific `Hands` in Blackjack.

### Constructors

- `BlackjackTable();`

  Uses the superclass constructor to create an empty `Table`.

### Methods

-
  ```
  void placeBet(Bet bet,
                Hand hand)
      throws InvalidBet;
  ```

  Updates the given *`hand`* to reference the given *`bet`*. Then uses the superclass `placeBet` to add this bet to the list of working bets.

- `public String toString();`

## Hand Rework

`Hand` contains a collection of individual `Cards`, and determines an appropriate total point value for the hand.

### Fields

- `List theCards = null;`

  Holds the individiual `Cards` of this hand.

- `Card theAce = null;`

  Holds a reference to one card with different hardValue and softValue. Typically, this will be first ace we are dealt. However, there may be a game variation in which cards other than aces present varying point totals.

- `Bet theAnte = null;`

  Holds a reference to the ante `Bet` for this hand. When this hand is resolved, the associated bet is paid and removed from the table.

### Constructors

- `Hand();`

  Creates an empty hand. The `theCards` variable is initialized to an empty LinkedList, and the `theAce` is reset to `null`.

- `Hand(Card aCard);`

  Uses the default constructor to create an empty hand. Then uses the `add` to add this card to the hand.

## Methods

- `public void add(Card aCard);`

  Add this card to the `theCards` list. If `theAce` is `null` and *`aCard`* has a different point total for `hardValue` and `softValue`, then save this card in `theAce`.

- `public int value();`

  Computes the point value of this hand. First, it sums the hard value of each card. If `theAce` is `null`, then there is no ace, and this is the final total that is returned.

  When there is an ace, we'll need to compute the soft total for the hand. The best way to to this is to use `hardTotal` - `theAce.hardValue()` + `theAce.softValue()`. Typically, the soft total is 10 more than the hard total, but the responsibility for providing the value belongs with `Card`, not this class. If the hand's soft total is 21 or less, this is returned. Otherwise, the hard total is returned.

- `public int size();`

  Returns the number of cards in the hand, the size of the `List`.

- `public boolean blackjack();`

  Returns true if this hand has a size of two and a value of 21.

- `public boolean busted();`

  Returns true if this hand a value of over 21.

- `public Iterator iterator();`

  Returns an iterator over the cards of the `List`.

- `public void setBet(Bet theAnt);`

  Sets the ante `Bet` that will be resolved when this hand is finished.

- `public Bet getBet();`

Returns the ante `Bet` for this hand.

- `public String toString();`

  Displays the content of the hand as a String with all of the card names.

## Deliverables

There are 4 deliverables for this exercise.

- The revised `Hand` class.
- A class which performs a unit tests of the `Hand` class. The unit test should create several instances of `Card`, `FaceCard` and `AceCard`, and add these to instances of `Hand`, to create various point totals. Additionally, the unit test should create a `Bet` and associate it with the `Hand`.
- The `BlackjackTable` class.
- A class which performs a unit tests of the `BlackjackTable` class. The unit test should create several instances of `Hand` and `Bet` to create multiple `Hands`, each with unique `Bets`.

# Chapter 40. BlackjackGame Class

**Table of Contents**

After reviewing the procedure provided in Typical Blackjack Game, we'll define the basic game class for Blackjack. This will require a stub class for a Blackjack Player. We'll also revisit the fundamental relationship between Game, Hand and Player. We'll invert our viewpoint from the Player containing a number of Hands to the Hands sharing a common Player.

## Overview

The sequence of operations in the game of Blackjack is quite complex. We can describe the game in either of two modes: as a sequential procedure or as a series of state changes. The sequential description means that the state is identified by the step that is next in the sequence. The state change description is what we used for Craps, see Table 21.1, "Craps Game States". Each state definition included a set of methods that represented conditions that could change state; and each `Throw` object invoked one of those methods, in effect, announcing a condition that caused a state change.

The sequential description of state, where the current state is defined by the step that is next, is the default description of state in most programming languages. While it seems obvious beyond repeating, it is important to note that each statement in a method changes the state of the application; either by changing state of the object that contains the method, or invoking methods of other, passive objects. In the case of an active class, this description of state as next statement is adequate. In the case of a passive class, this description of state doesn't work out well because passive classes have their state changed by other objects. For passive objects, instance variables and state objects are a useful way to track state changes.

In the case of Roulette, the cycle of betting and the game procedure were a simple sequence of actions. In the case of Craps, however, the game was only loosely tied to each the cycle of betting and throwing the dice, making the game state a passive part of the cycle of play. In the case of Blackjack, the cycle of betting and game procedure are more like Roulette.

Most of a game of Blackjack is simply sequential in nature: the initial offers of even money, insurance and splitting the hands are optional steps that happen in a defined order. When filling the player's `Hands`, there are some minor sub-states and state changes. Finally, when all of the player's `Hands` are bust or standing pat, the dealer fills their hand and the hands are finally resolved with no more player intervention. Most of the game appears to be a sequence of offers from the `Game` to the `BlackjackPlayer`; these are offers to place bets, or accept cards, or a combination of the two, for each of the player's `Hands`.

In Craps and Roulette, the `Player` was the primary collaborator with the Game. In Blackjack, however, focus shifts from the `Player` to the `Hand`. This changes the responsibilities of a `BlackjackPlayer`: the `Hand` can delegate certain offers to the `BlackjackPlayer` for a response. The `BlackjackPlayer` can become a plug-in strategy to the `Hand`, providing responses to offers of insurance, even money, splitting, doubling-down, hitting and standing pat. The `BlackjackPlayer`'s response will change the state of the `Hand`. Some state changes involve getting a card, and others involve placing a bet, and some involve a combination of the two.

We'll use the procedure definition in Typical Blackjack Game. Following this procedure, we see the following methods that a `Hand` and a `BlackjackPlayer` will need to respond to the various offers from the `BlackjackGame`. The first portion of the game involves the `BlackjackPlayer`, the second portion invovles one or more `Hands`. The collaboration is so intensive, we have created a kind of swimlane table, showing the operations each object must perform. This will allow us to expand `Hand` and `BlackjackTable` as well as define the interface for `BlackjackPlayer`.

Table 40.1. Blackjack Overall Collaboration

| BlackjackGame | Hand | BlackjackPlayer | BlackjackTable |
|---|---|---|---|
| calls player's placeBet | | creates empty Hand, creates initial Ante Bet | accepts the ante bet, associate with the hand |
| gets the initial hand; deal 2 cards to hand | add cards | returns the initial hand | |
| deal 2 cards to dealer's hand | add cards | | |
| gets up card from dealer's hand; if this card requires insurance, do the insurance procedure | return up card | | |
| | return true if two | | |

| | | | |
|---|---|---|---|
| iterate through all hands; is the given hand splittable? | return true if two cards of the same rank | returns a list iterator | |
| if the hand is splittable, offer a split bet | get the player's response; return it to the game | to split: create a split bet, and an empty hand; return the new hand | accept the split bet for the new hand |
| if splitting, move card and deal cards; loop back, looking for split offers | take a card out; add a card | | |
| iterate through all hands; if the hand is less than 21, do the fill-hand procedure | | returns a list iterator | |
| while the dealer's point value is 16 or less, deal another card | return point value of the hand; add a card | | |
| if the dealer busts, iterate through all hands resolving the ante as a winner | return point value of the hand | returns a list iterator | resolve bet as winner and remove |
| if the dealer does not bust, iterate through all hands comparing against the dealer's points, determining win, loss or push | return point value of the hand | returns a list iterator | resolve bet and remove |

There are a few common variation in this procedure for play. We'll set them aside for now, but will visit them in Chapter 42, *Variant Game Rules*.

The insurance procedure involves additional interaction between `Game` and the the `Player`'s initial `Hand`. The following is done only if the dealer is showing an ace.

Table 40.2. Blackjack Insurance Collaboration

| BlackjackGame | Hand | BlackjackPlayer | BlackjackTable |
|---|---|---|---|
| if player's hand is blackjack: offer even money | return true if 2 cards, soft 21 | to accept, return true | |
| if player accepted even money offer: change bet, resolve; end of game | | | update bet; resolve and remove bet |
| offer insurance | | to accept, create new bet; return true | accept insurance bet |
| if player accepted insurance offer: check dealer's hand; if blackjack, insurance wins, ante loses, game over; otherwise insurance loses | return point value | | resolve and remove bet |

The procedure for filling each `Hand` involves additional interaction between `Game` and the the `Player`'s initial `Hand`. An `Iterator` used for perform the following procedure for each individual player `Hand`.

Table 40.3. Blackjack Fill-Hand Collaboration

| BlackjackGame | Hand | BlackjackPlayer | BlackjackTable |
|---|---|---|---|

| | | | |
|---|---|---|---|
| if player's hand is blackjack: resolve ante bet | return true if 2 cards, soft 21 | | resolve and remove bet |
| while points less than 21, offer play options of double or hit; rejecting both offers is a stand. | return point value; pass offers to player | to double, increase the bet for this hand and return true; to hit, return true | update bet |
| if over 21, the hand is a bust | return point value | | resolve the ante as a loss |

There is some variation in this procedure for filling `Hands`. The most common variation only allows a double-down when the `Hand` has two cards.

Some of the offers are directly to the `BlackjackPlayer`, while others require informing the `BlackjackPlayer` which `Hand` is being played. One choice is to have the `BlackjackGame` make the offer to the `Hand`; when the `Hand` delegates this to the `BlackjackPlayer`, the `Hand` includes a reference to itself. The alternative is to have the `BlackjackGame` make the offer directly to the `BlackjackPlayer`, including a reference to the relevant `Hand`. While the difference is minor, we do need to more fully define the responsibilities of the hand, player and game. Since the `BlackjackGame` must iterate through the individual `Hands`, it makes sense for the `BlackjackGame` to make offers directly to the `BlackjackPlayer`, including a reference to the relevant `Hand`.

## Design

### BlackjackPlayer Class

`BlackjackPlayer` is a subclass of `Player` that responds to the various queries and inteactions with the game of Blackjack.

#### Fields

- `List hand ;`

  This list contains the initial `Hand` and any split hands that may be created.

#### Constructors

- `BlackjackPlayer(BlackjackTable aTable);`

  Uses the superclass to construct a basic `Player`. Uses the `newGame` to create an empty List fot the hands.

#### Methods

- `public void newGame();`

  Creates a new, empty List for the hands.

- `void placeBets();`

  Creates an empty `Hand` and adds it to the List of `Hand`. Creates a new ante Bet. Updates the `Table` with this `Bet` on the initial `Hand`.

- `public void getFirstHand();`

  Returns the initial `Hand`. This is used by the pre-split parts of the Blackjack game, where the player only has a single `Hand`.

- `public Iterator iterator();`

  Returns an iterator over the List of `Hands`.

- `public boolean evenMoney();`

  Returns `true` if this Player accepts the even money offer. The superclass always rejects this offer.

- `public boolean insurance();`

  Returns `true` if this Player accepts the insurance offer. In addition to returning true, the Player must also create the Insurance `Bet` and place it on the `BlackjackTable`. The superclass always rejects this offer.

- `public Hand split(Hand theHand);`

  Returns a new, empty `Hand` if this Player accepts the split offer for this `Hand`. The Player must create a new `Hand`, create an Insurance `Bet` and place the on the new `Hand` on the `BlackjackTable`. If the offser is declined, both set `splitDeclined` to `true` and return `null`.

- `public boolean doubleDown(Hand theHand);`

  Returns `true` if this Player accepts the double offer for this `Hand`. The Player must also update the `Bet` assocaited with this `Hand`. The superclass always rejects this offer.

- `public boolean hit(Hand theHand);`

  Returns `true` if this Player accepts the hit offer for this `Hand`. The superclass accepts this offer if the hand is 16 or less, and rejects this offer if the hand is 17 more more. This mimics the dealer's rules.

- `public String toString();`

  Displays the current state of the player, and the various hands.

## Hand Rework

`Hand` contains a collection of individual `Cards`, and determines an appropriate total point value for the hand. It responds to a number of requests from the `BlackjackGame`.

### Fields

- `List theCards = null;`

  Holds the individidual `Card`s of this hand.

- `Card theAce = null;`

  Holds a reference to one card with different hardValue and softValue. Typically, this will be first ace we are dealt. However, there may be a game variation in which cards other than aces present varying point totals.

- `Bet theAnte = null;`

  Holds a reference to the ante `Bet` for this hand. When this hand is resolved, the associated bet is paid and removed from the table.

- `Player thePlayer = null;`

  Holds a reference to the `Player` who owns this hand. Each of the various offers from the `Game` are delegated to the `Player`.

- `boolean splitDeclined = false;`

  Set to `true` if split was declined for a splittable hand. Also set to `true` if the hand is not splittable. The split procedure will be done when all hands return `true` for split declined.

### Constructors

- `Hand();`

  Creates an empty hand. The `theCards` variable is initialized to an empty LinkedList, and the `theAce` is reset to `null`.

- `Hand(Card aCard);`

  Uses the default constructor to create an empty hand. Then uses the `add` to add this card to the hand.

### Methods

- `public void add(Card aCard);`

  Add this card to the `theCards` list. If `theAce` is `null` and *`aCard`* has a different point total for `hardValue` and `softValue`, then save this card in `theAce`.

- `public Card remove();`

  Removed one card from the hand, which is the return value. This is used to move a `Card` when splitting a hand.

- `public int value();`

  Computes the point value of this hand. First, it sums the hard value of each card. If `theAce` is `null`, then there is no ace, and this is the final total that is returned.

  When there is an ace, we'll need to compute the soft total for the hand. The best way to to this is to use `hardTotal - theAce.hardValue() + theAce.softValue()`. Typically, the soft total is 10 more than the hard total, but the responsibility for providing the value belongs with `Card`, not this class. If the hand's soft total is 21 or less, this is returned. Otherwise, the hard total is returned.

- `public int size();`

  Returns the number of cards in the hand, the size of the `List`.

- `public boolean blackjack();`

  Returns `true` if this hand has a size of two and a value of 21.

- `public boolean busted();`

  Returns `true` if this hand a value of over 21.

- `public boolean splittable();`

  Returns `true` if this hand has a size of two and both `Cards` have the same rank. Also sets splitDeclined to `true` if the hand is not splittable.

- `public Iterator iterator();`

  Returns an iterator over the cards of the `List`.

- `public void setBet(Bet theAnte);`

  Sets the ante `Bet` that will be resolved when this hand is finished.

- `public Bet getBet();`

  Returns the ante `Bet` for this hand.

- `public Card getUpCard();`

  Returns the first `Card` from the List, the up card.

- `public String toString();`

  Displays the content of the hand as a String with all of the card names.

## BlackjackGame Class

`BlackjackGame` is a subclass of `Game` that manages the sequence of actions that define the game of Blackjack.

Note that a single cycle of play is one complete Blackjack game from the initial ante to the final resolution of all bets. Shuffling is implied before the first game and performed as needed.

### Fields

- `Shoe theShoe ;`

  This is the dealer's `Shoe` with the available pool of cards.

- `Hand dealer ;`

  This is the dealer's `Hand`.

### Constructors

-
  ```
  BlackjackGame(Shoe aShoe,
                BlackjackTable aTable);
  ```

  Constructs a new `BlackjackGame`, using a given `Shoe` for dealing `Cards` and a `BlackjackTable` for recording `Bets` that are associated with specific `Hands`.

### Methods

- `public void cycle();`

  A single game of Blackjack. This steps through the following sequence of operations.

  1. Call `newGame` to reset the player. Call `firstHand` and deal two cards into the player's initial hand.
  2. Reset the dealer's hand and deal two cards.
  3. Call `getUpCard` to get the dealer's up card. If this card returns `true` for the `offerInsurance`, then use the `insurance` method.
  4. Iterate through all `Hands`, assuring that no hand it splittable, or split has been declined for all hands. If a hand is splittable and split has not been declined, call the `Hand`'s `split` method. If the `split` method returns a new hand, remove a card from the original hand and deal to the new hand. Then deal two cards to each hand.
  5. Iterate through all `Hands` calling the `fillHand` method to check for blackjack, deal cards and check for a bust.
  6. While the dealer's hand value is 16 or less, deal another card.
  7. If the dealer's hand value is bust, resolve all ante bets as winners. The `OutcomeAnte` should be able to do this evaluation for a given `Hand` compared against the dealer's bust.
  8. Iterate through all hands with unresolved bets, and compare the hand total against the dealer's

total. The `OutcomeAnte` should be able to handle comparing the player's hand and dealer's total to determine the correct odds.

- `public void insurance();`

  Offers even money or insurance for a single game of blackjack. This steps through the following sequence of operations.

  1. Get the player's `firstHand`. Is this blackjack? If so, call `evenMoney`. If even money accepted, then move the ante bet to even money at 1:1. Resolve the bet as a winner. The bet will be removed, and the game will be over.
  2. Call `insurance`. If insurance declined, this method is done.
  3. If insurance was accepted, then check the dealer's hand. If the dealer has blackjack, the insurance bet is resolved as a winner, and the ante is a loser; the bets are removed and the game will be over. the dealer does not have blackjack, the insurance bet is resolved as a loser, and the ante remains. If insurance is declined, nothing is done.
- `public void fillHand(Hand theHand);`

  Fills one of the player's hands in a single game of Blackjack. This steps through the following sequence of operations.

  1. While points are less than 21, call `doubleDown` to offer doubling down. If accepted, deal one card, filling is done. If double down is declined, call `hit` to offer a hit. If accepted, deal one card. If both double down and hit are declined, filling is done.
  2. If the points are over 21, the hand is bust, and is resolved as a lower.
- `public String toString();`

  Displays the current state of the game, including the player, and the various hands.

## Deliverables

There are six deliverables for this exercise.

- The stub `BlackjackPlayer` class.
- A class which performs a unit test of the `BlackjackPlayer` class. Since this player will mimic the dealer, hitting a 16 and standing on a 17, the unit test can provide a variety of `Hands` and confirm which offers are accepted and rejected.
- The revised `Hand` class.
- A class which performs a unit tests of the `Hand` class. The unit test should create several instances of `Card`, `FaceCard` and `AceCard`, and add these to instances of `Hand`, to create various point totals. Since this version of `Hand` interacts with a `BlackjackPlayer`, additional offers of split, double, and hit can be made to the `Hand`.
- The revised `BlackjackGame` class.
- A class which performs a unit tests of the `BlackjackGame` class. The unit test will have to create a

`Shoe` that produces cards in a known sequence, as well as `BlackjackPlayer`. The `cycle` method, as described in the design, is too complex for unit testing, and needs to be decomposed into a number of simpler procedures.

# Chapter 41. Simple Blackjack Player Class

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Our objective is to provide variant player strategies. This chapter will upgrade our stub player class to give it a complete, working strategy. This simple player can serve as the superclass for more sophisticated strategies.

## Overview

In addition to the player's own hand, the player also has the dealer's up card available for determining their response to the various offers. The player has two slightly different goals: not bust and have a point total larger than the dealer's. While there is some overlap between these goals, these lead to two strategies based on the dealer's up card. When the dealer has a relatively low card (2 through 6), the dealer has an increased probability of going bust, so the player's strategy is to avoid going bust. When the dealer has a relatively high card (7 through 10), the dealer will probably have a good hand, and the player has to risk going bust when looking for a hand better than the dealer's.

We'll provide a few rules for a simple player strategy. This strategy is not particularly good. Any book on Blackjack, and a number of web sites, will have a superior strategy. A better strategy will also be considerably more complex. We'll implement this one first, and leave it to the student to research more sophisticated strategies.

1. Reject insurance and even money offers.
2. Accept split for aces and eights. Reject split on other pairs.
3. Hit any hand with 9 or less. The remaining rules are presented in the following table.

Table 41.1. Blackjack Player Strategy

| Player Shows | 2-6 | 7-10, Ace |
|---|---|---|
| 10 or 11 | hit | double down |
| hard 12 to 16 | stand | hit |
| soft 12 to 16 | hit | hit |

| | |
|---|---|
| 17 to 21 | stand stand |

These rules will boil down to short sequences of if-statements in the `split`, `hit` and `doubleDown` methods.

In some contexts, complex if-statements are deplorable. Specifically, complex if-statements are often a stand-in for proper allocation of responsibility. In this class, however, the complex if-statements implement a kind of index or lookup scheme. We have, for this exercise, 8 alternatives which depend on a two-dimensional index. One dimension contains four conditions that describe the player's hand. The other dimension involves two conditions that describe the dealer's hand. When we look at the various collections, we see that we can index by primitive types or object instances. In this case, we are indexing by conditions; we would have to map each condition to either a numeric code or a distinct object in order to eliminate the if-statements.

When we look at the conditions that describe the player's hand, these are clearly state-like objects. Each card can be examined and a state transition can be made based on the the current state and the card. After accepting a card, we would check the total and locate the appropriate state object. We can then use this state object to index into a collection.

When we look at the conditions that describe the dealer's hand, there are only two state-like objects. The dealer's op card can be examined, and we can locate the appropriate state object. We can use this state object to index into a collection.

The final strategy can be modeled as a collection with a two-part index. This can be nested collection objects, or a Map that uses a class like `NumberPair`. See the section called “NumberPair Class” for more information.

## Design

`SimpleBlackjackPlayer` is a subclass of `BlackjackPlayer` that responds to the various queries and inteactions with the game of Blackjack. This player implements a very simple strategy with a few: splits aces and eights, plays conservatively when the dealer shows 2 through 6 and plays more aggresively when the dealer shows 7 through ace.

### Methods

- `public boolean evenMoney();`

  Returns `true` if this Player accepts the even money offer. This player always rejects this offer.

- `public boolean insurance();`

  Returns `true` if this Player accepts the insurance offer. This player always rejects this offer.

- `public Hand split(Hand theHand);`

  Returns a new, empty `Hand` if this Player accepts the split offer for this `Hand`. The Player must create a new `Hand`, create an Insurance `Bet` and place the on the new `Hand` on the `BlackjackTable`. If the offser is declined, both set `splitDeclined` to `true` and return `null`. This player splits when the hand's card's ranks are aces or eights, and declines the split for all other ranks.

- `public boolean doubleDown(Hand theHand);`

  Returns `true` if this Player accepts the double offer for this `Hand`. The Player must also update the `Bet` assocaited with this `Hand`. This player tries to accept the offer when the hand points are 10 or 11, and the dealer's up card is 7 to 10 or ace. Otherwise the offer is rejected.

  Note that some games will restrict the conditions for a double down offer. For example, some games only allow double down on the first two cards. Other games may not allow double down on hands that are the result of a split.

- `public boolean hit(Hand theHand);`

  Returns `true` if this Player accepts the hit offer for this `Hand`.

  If the dealer up card is from 2 to 6, there are four choices for the player. When the hand is 11 or less, hit. When the hand is a hard 12 to 16, stand. When the hand is a soft 12 to soft 16 (hard 2 to hard 6), hit. When the hand is 17 or more, stand.

  If the dealer up card is from 7 to 10 or an ace, there are four choices for the player. When the hand is 11 or less, double down. When the hand is a hard 12 to 16, hit. When the hand is a soft 12 to soft 16 (hard 2 to hard 6), hit. When the hand is 17 or more, stand.

  Otherwise, if the point total is 9 or less, accept the hit offer.

## Deliverables

There are two deliverables for this exercise.

- The `SimpleBlackjackPlayer` class.
- A class which performs a unit test of the `SimpleBlackjackPlayer` class. The unit test can provide a variety of `Hands` and confirm which offers are accepted and rejected.

# Chapter 42. Variant Game Rules

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Deliverables

There are a number of variations in the sequence of game play offered by different casinos. In addition to having variations on the player's strategy, we also need to have variations on the casino rules.

## Overview

There are wide variations in the ways casinos conduct Blackjack games. We'll list a few of the variations we have heard of.

- **Additional Win Rule: Charlie.** Informal games may allow a "five-card Charlie" or "six-card Charlie" win. If the player's hand stretches to five (or six) cards, they are paid at 1:1.
- **Additional Offer: Surrender.** This variation allows the player to lose only half their bet. The offer is made after insurance and before splitting. Surrender against ace and 10 is a good strategy, if this offer is part of the game.
- **No Resplit.** This variation limits the player to a single split. In the rare event of another matching card, resplitting is not allowed.
- **No Double After Split.** This variation prevents the player from a double-down after a split.
- **Dealer Hits Soft 17.** This variation forces the dealer to hit soft 17 instead of standing. This tends in increase the house edge slightly.
- **Blackjack Pays 6:5.** This variation is often used in single-deck games. It limits the value of card-counting, since the house edge is stacked more heavily against the player.

The restrictions on splitting and doubling down are small changes to the offers made by a variation on `BlackjackGame`. The variations in the dealer's rules (hitting a soft 17) is also a small change to the `BlackjackGame`. Reducing the number of decks is an easy change to our application. Since our main application constructs the `Shoe` before constructing the `Game`, it can construct a single-deck `Shoe`. The variations in the payout odds, however, are somewhat more complex.

Changing the odds for the blackjack `Outcome`, will lead us to create a new subclass like `OutcomeAnte` with 6:5 odds for a blackjack instead of the 3:2 odds. Unfortunately, we construct the basic ante bet object in the `BlackjackPlayer`. In order to use a different class of bet, we would need to create a new class of `BlackjackPlayer`. This implies an entanglement between `BlackjackGame` and `BlackjackPlayer`. Uncoupling these two classes requires assigning the correct `OutcomeAnte` object to the `BlackjackPlayer`. This can be done when by the main application, or, by having the `BlackjackPlayer` get the proper `OutcomeAnte` object from the `BlackjackGame`. This allows players and games to evolve independently.

Uncoupling the `OutcomeAnte` from the `BlackjackPlayer` means that we will have to add a method to `BlackjackGame` that will return a proper instance of `OutcomeAnte` for the game variation. We will have to introduce a new `OutcomeAnteLowOdds` class that uses 6:5 odds instead of 3:2 odds. Our `getAnte` method can return either an instance of `OutcomeAnte` or `OutcomeAnteLowOdds`. Since these two classes are polymorphic, the rest of our application can ignore the distinction.

# Design

## BlackjackGame Rework

`BlackjackGame` is a subclass of `Game` that manages the sequence of actions that define the game of Blackjack.

Note that a single cycle of play is one complete Blackjack game from the initial ante to the final resolution of all bets. Shuffling is implied before the first game and performed as needed.

### Fields

- `Shoe theShoe ;`

  This is the dealer's `Shoe` with the available pool of cards.

- `Hand dealer ;`

  This is the dealer's `Hand`.

- `OutcomeAnte ante ;`

  This is the expected `OutcomeAnte` for this game variation. Generally, this is just an instance of `OutcomeAnte`; however, some game variations will subclass `OutcomeAnte` to provide different odds.

### Constructors

-
  ```
  BlackjackGame(Shoe aShoe,
                BlackjackTable aTable);
  ```

  Constructs a new `BlackjackGame`, using a given `Shoe` for dealing `Cards` and a `BlackjackTable` for recording `Bets` that are associated with specific `Hands`. Constructs `ante` for use by inividual players.

### Methods

- `public OutcomeAnte getAnte();`

  Returns the value of `ante`, with the expected ante object for this game. The superclass returns an instance of `OutcomeAnte`; however, some game variations will subclass `OutcomeAnte` to provide different odds.

- `public void cycle();`

  A single game of Blackjack. This steps through the following sequence of operations.

  1. Call `newGame` to reset the player. Call `firstHand` and deal two cards into the player's initial hand.

2. Reset the dealer's hand and deal two cards.
3. Call `getUpCard` to get the dealer's up card. If this card returns `true` for the `offerInsurance`, then use the `insurance` method.
4. Iterate through all `Hands`, assuring that no hand it splittable, or split has been declined for all hands. If a hand is splittable and split has not been declined, call the `Hand`'s `split` method. If the `split` method returns a new hand, remove a card from the original hand and deal to the new hand. Then deal two cards to each hand.
5. Iterate through all `Hands` calling the `fillHand` method to check for blackjack, deal cards and check for a bust.
6. While the dealer's hand value is 16 or less, deal another card.
7. If the dealer's hand value is bust, resolve all ante bets as winners. The `OutcomeAnte` should be able to do this evaluation for a given `Hand` compared against the dealer's bust.
8. Iterate through all hands with unresolved bets, and compare the hand total against the dealer's total. The `OutcomeAnte` should be able to handle comparing the player's hand and dealer's total to determine the correct odds.

- `public void insurance();`

  Offers even money or insurance for a single game of blackjack. This steps through the following sequence of operations.

  1. Get the player's `firstHand`. Is this blackjack? If so, call `evenMoney`. If even money accepted, then move the ante bet to even money at 1:1. Resolve the bet as a winner. The bet will be removed, and the game will be over.
  2. Call `insurance`. If insurance declined, this method is done.
  3. If insurance was accepted, then check the dealer's hand. If the dealer has blackjack, the insurance bet is resolved as a winner, and the ante is a loser; the bets are removed and the game will be over. the dealer does not have blackjack, the insurance bet is resolved as a loser, and the ante remains. If insurance is declined, nothing is done.

- `public void fillHand(Hand theHand);`

  Fills one of the player's hands in a single game of Blackjack. This steps through the following sequence of operations.

  1. If this hand is a blackjack, resolve it as a winner; the `OutcomeAnte` should be able to do this evaluation for a given `Hand`.
  2. While points are less than 21, call `doubleDown` to offer doubling down. If accepted, deal one card, filling is done. If double down is declined, call `hit` to offer a hit. If accepted, deal one card. If both double down and hit are declined, filling is done.
  3. If the points are over 21, the hand is bust, and is resolved as a lower.

- `public String toString();`

  Displays the current state of the game, including the player, and the various hands.

## OutcomeAnteLowOdds Design

`OutcomeAnteLowOdds` contains a single outcome for the blackjack ante bet that has a number of different odds, and the odds used depend on the `Hand`. This variant implements 6:5 blackjack odds instead of the more standard 3:2 odds.

### Methods

-
  ```
  double winAmount(int amount);
  ```

  In Python, this method should raise the `NotImplementedException`. In Java, this method can throw the `NoSuchMethedException`. This method should not be called for this kind of outcome; any attempt to do so is a serious design error.

-
  ```
  double winAmount(int amount,
                   Hand event);
  ```

  Checks the `Hand` to locate the correct odds. Blackjack uses 6:5, other hands use 1:1. Returns the product of the appropriate odds numerator by the given amount, divided by the odds denominator.

-
  ```
  double winAmount(int amount,
                   Hand event,
                   int dealerPoints);
  ```

  Checks the `Hand` to locate the correct odds. If the *`event`* point value is greater than the *`dealerPoints`*, odds are 1:1; return the product of the appropriate odds numerator by the given amount, divided by the odds denominator. If the point values are equal this is a push, simply return the bet *`amount`*.

- An easy-to-read String output method should return a String representation of the name and the odds. A form that looks like `Ante (6:5)` works nicely.

## OneDeckGame Class

`OneDeckGame` is a subclass of `BlackjackGame` that manages the sequence of actions for a one-deck game of Blackjack with a 6:5 blackjack `OutcomeAnteLowOdds`. Typically, this is built with a one-deck instance of `Shoe`.

### Fields

-
  ```
  OutcomeAnte ante ;
  ```

  This is the expected `OutcomeAnte` for this game variation. For this game variations this is an instance of `OutcomeAnteLowOdds`.

### Constructors

-
  ```
  BlackjackGame(Shoe aShoe,
                BlackjackTable aTable);
  ```

  Constructs a new `BlackjackGame`, using a given `Shoe` for dealing `Cards` and a `BlackjackTable` for recording `Bets` that are associated with specific `Hands`. Constructs `ante` for use by inividual players.

## Deliverables

There are seven deliverables for this exercise.

- The revised `BlackjackGame` class. This will provide the additional `getAnte` method that returns the proper `OutcomeAnte` object.
- The revised unit test of the `BlackjackGame` class to add a test for the new `getAnte` method.
- A revised `BlackjackPlayer` class. This revision will use the `getAnte` method of the `BlackjackGame` to return the recommended ante object. The existing unit tests should all work without modification.
- The `OutcomeAnteLowOdds` class.
- A class to perform a unit test of the `OutcomeAnteLowOdds` class.
- The `OneDeckGame` class.
- A class to perform a unit test of the `OneDeckGame` class.

# Chapter 43. Conclusion

The game of Blackjack has given us an opportunity to further extend and modify an application with a considerable number of classes and objects. These exercises gave us an opportunity to work from a base of software, extending and refining the design.

We omitted concluding exercises which would integrate this package with the `Simulator` and collect statistics. This step, while necessary, doesn't include many interesting design decisions. The final deliverable should be a working application that parses command-line parameters, creates the required objects, and creates an instance of `Simulator` to collect data.

We have specifically omitted delving into the glorious details of specific player strategies. We avoided these details for two reasons.

- **Intellectual Property.** We didn't create any strategies. Rather than get permission to quote existing blackjack strategies, we leave it to the interested student to either buy any of the available books on Blackjack or download a strategy description from the Internet.
- **Irrelevant Complexity.** We find that all of the detailed programming required to implement a particular strategy doesn't have too much to do with object-oriented design. Rather, it is an exercise in construction of detailed if-statements. It appears to be the wrong focus for learning OO design.

# Appendix A. Python `unittest` Testing

Python `unittest` requires that we build a test module separate from the application class we're testing. The test module will have one more more `TestCase` classes, each of which has one or more test methods.

Generally, we'll organize our project directory to have a `test` directory and a `src` directory.

Let's assume we've built two classes in some chapter; pretend that we're building `Card` and `Deck`. One class defines a standard playing card and the other class deals individual card instances. We need unit tests for each class.

Generally, unit tests are taken to mean that a class is tested in isolation. In our case, a unit test for Card is completely isolated.

Since our Deck class depends on Card, we have a difficult choice to make. Either we have to create a Mock Card that can be used to test Deck in complete isolation, or our Deck test will depend on both Deck and Card. The choice depends on the relative complexity of Card, and whether or not Deck and Card will evolve independently.

One approach to unit testing is to build the tests first, then write a class which at least doesn't crash, but may not pass all the tests. Once we have this in place, we can now debug the tests until everything looks right. This is called test-driven development.

We'd start with unittest files in the `test` directory of our project. In this case, we'd have `testCard.py` and `testDeck.py`. We also need skeleton files in our `src` directory: `card.py` and `deck.py`.

**Example A.1. testCard.py**

```
import unittest
import card
class TestCard( unittest.TestCase ):
    def setUp( self ):
        self.aceClubs= card.Card(1,card.Clubs)
        self.twoClubs= card.Card(2,card.Clubs)
        self.tenClubs= card.Card(10,card.Clubs)
        self.kingClubs= card.Card(13,card.Clubs)
        self.aceDiamonds= card.Card(1,card.Diamonds)
    def testString( self ):
        self.assertEquals( " AC", str(self.aceClubs) )
        self.assertEquals( " 2C", str(self.twoClubs) )
        self.assertEquals( "10C", str(self.tenClubs) )
    def testOrder( self ):
        self.assertTrue( self.tenClubs < self.kingClubs )
        self.assertFalse( self.tenClubs >= self.kingClubs )
        self.assertTrue( self.kingClubs < self.aceClubs )
        self.assertTrue( self.aceClubs == self.aceDiamonds )

if __name__ == "__main__":
    unittest.main()
```

❶ Generally, we create a number of object instances in the setup method. In this case, we created five distinct `Card` instances. These object constructors imply several things in our `card` module.

- There will be a set of manifest constants for the suits: `Clubs`, `Diamonds`, `Hearts` and `Spades`.
- The constructor (`__init__`) for `Card` will accept a rank and a suit constant.

Note that we didn't write tests to create all suits or all ranks. We can add these later. In some cases, where we are working in large teams, we may need to produce tests which exhaustively enumerate all possibe alternatives. For the purposes of learning OO design, we only need to sketch out our class by defining the tests it must pass.

❷ In `testString`, we exercise the `__str__` method of the `Card` class to be sure that it formats cards correctly. These tests tell us what the formatting algorithm will look like.

❸ In `testOrder`, we exercise the `__cmp__` method of the `Card` class to be sure that it compares card ranks correctly. Note that we have explicitly claimed that the equality test only checks the rank and ignores the suit; this is typical for Blackjack, but won't work well for Bridge or Solitaire.

Note that we didn't exhaustively test all possible comparisons among the four cards we defined. We only need to execute the various paths within the `__cmp__` method. When we initially create the test class, we may not have written the `Card` class yet. What we have to do is develop enough tests to get started, and add tests as we start writing our `Card` class.

❹ This is the standard main program for unittest modules.

Our initial Card class needs to have just enough of an API to allow the tests to run. Here's our skeleton Card class.

**Example A.2. card.py**

```
Diamonds= "D"
Clubs= "C"
Spades= "S"
Hearts= "H"
class Card( object ):
    def __init__( self, rank, suit ):
        pass
    def __str__( self ):
        return ""
    def __cmp__( self ):
        return 0
```

This class will -- minimally -- participate in the testing. It won't pass many tests, but it serves as a basis for developing the class implementation.

# Appendix B. Python `doctest` Testing

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Python doctest requires that we build our class, exercise it in the Python interpreter, then put snippets of the interactive log into our docstrings. Once we've put the expected results in our docstrings, The doctest utility will then find these log snippets and assure that our classes actually do what's advertised.

One approach to unit testing is to build the tests first, then write a class which at least doesn't crash, but may not pass all the tests. Once we have this in place, we can now debug the tests until everything looks right. This is called test-driven development, because the test cases come first, driving the rest of the work.

The test-driven approach doesn't fit well with `doctest`. It's very difficult to develop the test output without having the class available to exercise interactively. Also, we don't want to put comprehensive test scripts into our class docsting; they can easily get too long to be useful.

The `doctest` capability has to be used judiciously. First, the class has to work. Second, we need to pick essential features for demonstration in the doctest comments. Finally, we have to carefully work back and forth between the interactive Python interpreter and our module file to put those snippets of expected results into the comments.

Let's assume we've built two classes in some chapter; pretend that we're building `Card` and `Deck`. One class defines a standard playing card and the other class deals individual card instances. We'll define some minimal doctests.

## Develop the Class

The first step is to develop our baseline class. Here's a module that seems like it works.

**Example B.1. card.py - Initial**

```
Clubs="C"
Diamonds="D"
Hearts="H"
Spades="S"
class Card( object ):
    def __init__( self, rank, suit ):
        self.rank= 14 if rank == 1 else rank
        self.suit= suit
    def __str__( self ):
        if self.rank == 14:
            return " A%s" % ( self.suit, )
        return "%2d%s" % ( self.rank, self.suit )
    def __cmp__( self, other ):
        return cmp( self.rank, other.rank )
```

## Exercise the Class

Once we have the class, we need to exercise it using interactive Python. Here's what we saw.

```
Python 2.5.1 (r251:54863, Jan 17 2008, 19:35:17)
[GCC 4.0.1 (Apple Inc. build 5465)] on darwin
Type "help", "copyright", "credits" or "license" for more information.

>>> from card import *
>>> Card(1,Diamonds)
```

```
<card.Card object at 0x619a50>
>>> aceDiamonds=Card(1,Diamonds)
>>> str(aceDiamonds)
' AD'
```

During our session, small parts of the script show the preferred use cases for our class. We copy these from the interactive session and paste them into our class docstrings.

## Update the Docstrings

After we have some output that shows correct behavior of our class, we can put that output into the class docstrings. Here's our updated `card.py` module with doctest comments.

**Example B.2. card.py - Revised**

```
Clubs="C"
Diamonds="D"
Hearts="H"
Spades="S"
class Card( object ):
    def __init__( self, rank, suit ):
        self.rank= 14 if rank == 1 else rank
        self.suit= suit
    def __str__( self ):
        """
        >>> aceDiamonds=Card(1,Diamonds)
        >>> str(aceDiamonds)
        ' AD'
        """
        if self.rank == 14:
            return " A%s" % ( self.suit, )
        return "%2d%s" % ( self.rank, self.suit )
    def __cmp__( self, other ):
        return cmp( self.rank, other.rank )
```

## Add the Test Framework

There are two `doctest` frameworks. Doctest can be used for "stand-alone" testing. It can also be incorporated into `unittest` testing.

The general approach to stand-alone testing is to add the following to a module. When you run the module, it executes all `doctest` strings found throughout the module. Tests will pass silently. Any output is a failure of some kind.

```
def _test():
    import doctest
    doctest.testmod()

if __name__ == "__main__":
    _test()
```

## Mixed `unittest` and `doctest`

A more complete approach is to use `unittest` for most testing and `doctest` to emphasize specific use cases in the docstrings. When doing this, you'll have a test module that looks something like the following.

**Example B.3. testCards.py**

```
import unittest
import doctest
import card

class TestCard( unittest.TestCase ):
    def setUp( self ):
        self.aceClubs= card.Card(1,card.Clubs)
        self.twoClubs= card.Card(2,card.Clubs)
        self.tenClubs= card.Card(10,card.Clubs)
        self.kingClubs= card.Card(13,card.Clubs)
        self.aceDiamonds= card.Card(1,card.Diamonds)
    def testString( self ):
        self.assertEquals( " AC", str(self.aceClubs) )
        self.assertEquals( " 2C", str(self.twoClubs) )
        self.assertEquals( "10C", str(self.tenClubs) )
    def testOrder( self ):
        self.assertTrue( self.tenClubs < self.kingClubs )
        self.assertFalse( self.tenClubs >= self.kingClubs )
        self.assertTrue( self.kingClubs < self.aceClubs )
        self.assertTrue( self.aceClubs == self.aceDiamonds )

if __name__ == "__main__":
    suite1 = doctest.DocTestSuite(card)
    suite2 = unittest.defaultTestLoader.loadTestsFromTestCase( TestCard )
    suite1.addTest( suite2 )
    runner = unittest.TextTestRunner()
    runner.run(suite1)
```

❶ We must import both `doctest` and `unittest` as well as the module we are testing.

❷ Here's a unittest sequence for our class. This is intended to be comprehensive and test every feature of our class. Additionally, the class docstrings have additional doctest sequences that we must also validate.

❸ To run a mixture of `doctest` and `unittest`, we have to create a single `TestSuite` object that incorporates both kinds of tests. We can create a `DocTestSuite` from a module. We can create a TestSuite by loading tests from a `TestCase`. We then build a test runner, and turn it lose on our suite of tests.

# Appendix C. Java `JUnit` Testing

Java `JUnit` requires that we build a test class separate from the application class we're testing. The test class will be a subclass of `TestCase`, which has one or more test methods. Generally, we'll organize our project directory to have a `test` directory and a `src` directory.

Let's assume we've built two classes in some chapter; pretend that we're building `Card` and `Deck`. One class defines a standard playing card and the other class deals individual card instances. We need unit tests for each class.

Generally, unit tests are taken to mean that a class is tested in isolation. In our case, a unit test for Card is completely isolated.

Since our Deck class depends on Card, we have a difficult choice to make. Either we have to create a Mock Card that can be used to test Deck in complete isolation, or our Deck test will depend on both Deck and Card. The choice depends on the relative complexity of Card, and whether or not Deck and Card will evolve independently.

One approach to unit testing is to build the tests first, then write a class which at least doesn't crash, but may not pass all the tests. Once we have this in place, we can now debug the tests until everything looks right. This is called test-driven development.

We'd start with unittest files in the `test` directory of our project. In this case, we'd have `testCard.py` and `testDeck.py`. We also need skeleton files in our `src` directory: `card.py` and `deck.py`.

**Example C.1. TestCard.java**

```
import junit.framework.TestCase;
public class TestCard extends TestCase {
    Card aceClubs, twoClubs, tenClubs, kingClubs, aceDiamonds;
    public TestCard() {
        super();
    }
    public void setUp() {
        aceClubs= new Card(1,Card.Clubs);
        twoClubs= new Card(2,Card.Clubs);
        tenClubs= new Card(10,Card.Clubs);
        kingClubs= new Card(13,Card.Clubs);
        aceDiamonds= new Card(1,Card.Diamonds);
    }
    public void testString() {
        assertEquals( " AC", aceClubs.toString() );
        assertEquals( " 2C", twoClubs.toString() );
        assertEquals( "10C", tenClubs,toString() );
    }
    public void testOrder() {
        assertTrue( tenClubs.compareTo(kingClubs) < 0 );
        assertFalse( tenClubs.compareTo(kingClubs) >= 0 );
        assertTrue( kingClubs.compareTo(aceClubs) < 0 );
        assertTrue( aceClubs.compareTo(aceDiamonds) == 0 );
    }
}
```

❶ Generally, we create a number of object instances in the setup method. In this case, we created five distinct `Card` instances. These object constructors imply several things in our `Card` class.

- There will be a set of manifest constants for the suits: `Clubs`, `Diamonds`, `Hearts` and `Spades`. These will be static, final values in the class definition.

- The constructor for `Card` will accept a rank and a suit constant.

Note that we didn't write tests to create all suits or all ranks. We can add these later. In some cases, where we are working in large teams, we may need to produce tests which exhaustively enumerate all possibe alternatives. For the purposes of learning OO design, we only need to sketch out our class by defining the tests it must pass.

❷ In `testString`, we exercise the `toString` method of the `Card` class to be sure that it formats cards correctly. These tests tell us what the formatting algorithm will look like.

❸ In `testOrder`, we exercise the `compareTo` method of the `Card` class to be sure that it compares card ranks correctly. Note that we have explicitly claimed that the equality test only checks the rank and ignores the suit; this is typical for Blackjack, but won't work well for Bridge or Solitaire.

Note that we didn't exhaustively test all possible comparisons among the four cards we defined. We only need to execute the various paths within the `compareTo` method. When we initially create the test class, we may not have written the `Card` class yet. What we have to do is develop enough tests to get started, and add tests as we start writing our `Card` class.

Our initial Card class needs to have just enough of an API to allow the tests to run. Here's our skeleton Card class.

**Example C.2. Card.java**

```
public class Card {
    public int rank;
    public String suit;
    public static final String Clubs= "C";
    public static final String Diamonds= "D";
    public static final String Hearts= "H";
    public static final String Spades= "S";
    public Card( int rank, String suit ) {
        this.rank= rank;
        if( rank == 1 ) {
            this.rank= 14;
        }
        this.suit= suit;
    }
    public String toString() {
        if( this.rank == 14 ) {
            return " A" + this.suit;
        }
        return Integer.toString( this.rank ) + this.suit;
    }
    public int compareTo( Card other ) {
        return this.rank - other.rank;
    }
}
```

This class will -- minimally -- participate in the testing. It won't pass many tests, but it serves as a basis for developing the class implementation.

Here is an example of compiling and running this test from the command line. Your IDE will generally have a JUnit runner built-in. We can't cover the various IDE (NetBeans, Eclipse, JBuilder, Visual Studio, etc.) in this book, so we've provided just the command-line equivalent.

```
javac -cp junit-4.4.jar:. *.java
java -cp junit-4.4.jar:. junit.textui.TestRunner TestCard
..
Time: 0.003

OK (2 tests)
```

# Appendix D. Python `Epydoc` Documentation

**Table of Contents**

Application Program Interface (API) documentation is absolutely essential. The easiest and most reliable way to produce this documentation is by using a tool that examines the source itself and develops the document directly from the programs. By using cleverly formatted Python docstrings, we can augment that analysis with easy-to-understand descriptions.

In the case of Python, there are several tools for extracting documentation from the source. We'll look at just one, Epydoc. Epydoc is available at `http://epydoc.sourceforge.net/`.

Generally, the workflow has the following outline.

1. Develop the skeleton class.

2. Develop unit tests for most features.

3. Rework the class until it passes the unit tests. This may involve adding or modifying tests as we understand the class better. This also involves writing docstrings for modules, classes and methods.

4. Revisit the modules, classes and methods, finishing each description using the Epytext markup language. We won't cover all of this language, just enough to provide a sense of how the tool is used to make clean, professional API documentation.

   Basic Epytext rules allow you to have a nice outline, with numbered and bulleted lists. You can include code examples and doctest results, also. With the "inline" markup, you can specify italic, bold or code samples.

   Additionally, Epytext uses "field" markup to tie your documentation to specific pieces of Python syntax. This includes method parameters, return values, class instance variables, module variables, etc.

5. Run Epydoc to create the documentation. Fix any errors in your Epytext. Also, rework the documentation as necessary to be sure that you've capture important information about the class, the methods, the design decisions.

When you install Epydoc, it creates a script that you can use. To run Epydoc, you'll use a command similar to the following.

```
epydoc -v -o apidoc card.py
```

The `-v` option provides detailed debugging information for incorrectly formatted docstrings. The `-o` option defines the directory to which the documentation is written. The arguments (in this case, `card.py`) is a list of package directories or module files to be documented.

## Basic Epytext Markup

We write our module, class and method docstrings using the Epytext markup language. Generally, a source document contains two elements: the content itself, and markup that shows the structure or meaning of the content. HTML, SGML and XML are all markup languages that use explicit tags to bracket each element of the document. HTML and XML can be rather complex and difficult to prepare.

The Epytext markup language is one of many *structured text* markup languages, where simple indentation and formatting rules are used to interpret your documetation. These rules are how Epydoc deduces the structure of your document (sections, list, etc.) and the presentation (bold, italic, or font changes.) These rules are — generally — pretty simple rules that plain text documents have been using since documents were first stored on computers.

Epytex is described as a lightweight markup language: it has just a few rules. An alternative is to use ReStructured Text (RST) markup instead of Epytext markup. RST has a more richer set of rules, many of which overlap with Epytext. The main benefit of both Epytext and RST is that you don't have to learn HTML. You use a few formatting rules, and Epydoc manufactures HTML for you.

**Document Structure.** Generally, you must write in paragraphs. A blank line is the end of one paragraph and the beginning of another. Also, different indentation will signal paragaph changes. The indent rule is handy for making bullet lists or numbered lists. A line that is indented and begins with `-` is a bulleted list. A line that starts with digits and periods is a numbered list. Lists can nest within each other.

If you need to have sections and subsections (you'll almost always do this in the docstring for a module or package), you "underline" the title with lines of `===`, `---` or `~~~`.

If you have a paragraph which begins with `>>>`, this is formatted as a "literal" block by Epydoc. It is not treated as text where line boundaries are flexible.

Also, if you have a paragraph with ends with `::`, this means that the following paragaphs will be indented and will be a code sample of some kind. The code sample will be formatted as literal text.

Generally, the first paragraph must be a pithy summary of the material to follow. This paragraph will often be used in overviews and index pages.

For example, our module document might look like this.

```
#!/usr/bin/env python
"""The testcard module includes a number of unit tests for the Card
```

```
and Deck classes in the card module.

Overview
========

This module tests the following classes:

    - Card

    - Deck

Card Tests
----------

...more documentation...

Deck Tests
----------

...and yet more...

Usage
=====

This module uses the standard text runner, so it can be executed
from the command line as follows::

    python testcard.py

"""
```

❶ This is the overview paragraph. It summarizes the module in a single sentence.

❷ This is a section heading. The highest level of the outline is underlined with ='s. The second level is underlined with -'s and the third level uses ~'s. If you need more complex outlining, you probably shouldn't be including this with your program, but writing a separate book with more sophisticated tools.

❸ This is a bullet list. Simply indent, and begin the paragraph with `-`. Lists can be nested, Epydoc will work this out based on the indentation of the various sublists.

❹ This is a literal block. The previous paragraph ended with `::`. The following material is indented to show what should be formatted specially.

**Text Formatting, or Inline Markup.** In addition to basic document structure rules, Epytext includes a way to show that a span of characters should be formatted specially. This is sometimes called Inline Markup because it is within the structural markup.

- `I{`*`some text`*`}` marks the text as *italic*.
- `B{`*`some text`*`}` marks the text as **bold**.
- `C{`*`some text`*`}` marks the characters as "code", and a `fixed width` font should be used.
- `L{`*`name`*`}` generates a cross-reference to the given python name: a method, variable, class, module or

package.

- `U{`*`http:...`*`}` generates a hyperlink to the given URI.

Here's an example of a paragraph using some inline markup to make some characters italic, other bold, and still others a fixed-width find that makes them looke like code.

```
This method computes the square root of a number, I{n}.
It returns a value, I{r} such that I{r}C{**2 = }I{n}.

B{NOTE.} Square root of a negative number will raise an C{TypeError} exception.
```

## Epytext Field Markup

Epydoc Field markup is primarily used to tie your documentation directly to Python language structures. Field markup is a separate paragraph that starts with `@` and a tag. We won't cover all of the tags, just enough to produce basic documentation.

Field markup also provides several standard kinds of standard "formal paragraphs" within your document. We'll look at these separately.

**Functions and Method Functions.** The following tags are used to define detailed features of a method function.

- `@param p:` *`some text`*

  This tag defines a positional parameter, `p`.

- `@return:` *`some text`*

  This tag defines the return value from the method function.

- `@keyword p:` *`some text`*

  This tag defines a keyword parameter, `p`.

Here's an example of a method function docstring that uses `@param` tags.

```
    def __init__( self, rank, suit ):
        """Build a card with a given rank and suit.
        @param rank: numeric rank, ace is 1, 2-13 for 2 though King.
        @param suit: String suit, use one of the module constants.
        """
        self.rank= 14 if rank == 1 else rank
        self.suit= suit
```

**Classes and Modules.** The following tags are used to define specific variables in a module or class.

- `@ivar v:` *`some text`*

This tag defines an instance variable of a class. Generally, this will be in the class level docstring, and will refer to one of the class's `self.` variables.

- `@var v:` *`some text`*

  This tag defines a global variable of a module. Generally, this will be in the module docstring, and will refer to one of the global variables created by the module.

Here's an example of a class definition docstring that uses `@ivar` tags.

```
class Card( object ):
    """A single playing card, suitable for Blackjack or
    Poker.  While a suit is retained, it doesn't figure into
    the ordering of cards, as it would in Bridge.

    B{Reminder.} The internal rank of an Ace is 14.  The constructor,
    however, expects a value of 1.

    @ivar rank: the numeric rank of the card.  2-13, with ace as 14.
    @ivar suit: the string suit of the card.
    """
```

**Standard Paragraphs.** There are several kinds of standard paragraphs that are part of any well-written document set. These include things like

- Related Topics. Use the `@see:` tag to generate a "Related Topics" paragaph with references to other documents.
- Notes and Warnings. You can use the `@note:`, `@attention:`, `@bug:`, and `@warning:` tags to generate standard types of labeled paragraphs.
- Status. You can track the development and deployment status of your programs with tags like `@version:`, `@todo:`, `@deprecated:`, `@since:`, `@status:`, and `@change:`.
- Bibliographic Information. You can provide standard publication information with tags like `@author:`, `@organization:`, `@copyright:`, `@license:` and `@contact:`.

Here's an example of a module document with some standard paragraphs.

```
#!/usr/bin/env python
"""The testcard module includes a number of unit tests for the Card
and Deck classes in the card module.

@author: S. Lott

@license: U{http://creativecommons.org/licenses/by-nc-nd/3.0/us/}

@attention: The definition of Card is focused on Blackjack and Poker, where suit doesn't
matter.

"""
```

# Epydoc Example

Here's an example of our Card class with Epydoc documentation folded in.

**Example D.1. card.py**

```
#!/usr/bin/env python
"""The card module defines the Card class and constants
for the four suits.
@license: U{http://creativecommons.org/licenses/by-nc-nd/3.0/us/}
@var Clubs: Used to build Cards in the clubs suit
@var Diamonds: Used to build Cards in the diamonds suit
@var Hearts: Used to build Cards in the hearts suit
@var Spades: Used to build Cards in the spades suit
"""
Clubs="C"
Diamonds="D"
Hearts="H"
Spades="S"
class Card( object ):
    """A single playing card, suitable for Blackjack or
    Poker.  While a suit is retained, it doesn't figure into
    the ordering of cards, as it would in Bridge.

    @note: The internal rank of an Ace is 14.  The constructor,
    however, expects a value of 1.
    @ivar rank: the numeric rank of the card.  2-13, with ace as 14.
    @ivar suit: the string suit of the card.
    """
    def __init__( self, rank, suit ):
        """Build a card with a given rank and suit.
        @param rank: numeric rank, ace is 1, 2-13 for 2 though King.
        @param suit: String suit, use one of the module constants.
        """
        self.rank= 14 if rank == 1 else rank
        self.suit= suit
    def __str__( self ):
        """String representation for a Card.
        @return: string

        >>> aceClubs= Card( 1, Clubs )
        >>> str(aceClubs)
        ' AC'
        >>> tenClubs= Card( 10, Clubs )
        >>> str(tenClubs)
        '10C'
        """
        if self.rank == 14:
            return " A%s" % ( self.suit, )
        return "%2d%s" % ( self.rank, self.suit )
    def __cmp__( self, other ):
        """Compare the rank of two cards, ignoring suit
        @param other: the other card to compare with
        @return: <0 if self < other, >0 if self > other,
        0 if they're the same rank.
        >>> Card( 1, Diamonds ) == Card( 1, Spades )
        True
        >>> Card( 1, Diamonds ) == Card( 10, Spades )
        False
        >>> Card( 2, Clubs ) < Card( 13, Clubs )
        True
        >>> Card( 13, Clubs ) < Card( 1, Clubs )
        True
        """
        return cmp( self.rank, other.rank )
```

❶ The module-level docstring, including `@license:` and `@var` *`name`*`:` tags.

❷ The class-level docstring, including `@note:` and `@ivar` *`name`*`:` tags.

❸ A method function docstring, including `@param` *`name`*`:` tags.

# Appendix E. Java `javadoc` Documentation

**Table of Contents**

Application Program Interface (API) documentation is absolutely essential. The easiest and most reliable way to produce this documentation is by using a tool that examines the source itself and develops the document directly from the programs. By using cleverly formatted comments, we can augment that analysis with easy-to-understand descriptions.

In the case of Java, the Javadoc tool is the most common way for extracting documentation from the source.

Generally, the workflow has the following outline.

1. Develop the skeleton class.

2. Develop unit tests for most features.

3. Rework the class until it passes the unit tests. This may involve adding or modifying tests as we understand the class better. This also involves writing comments for each class and method.

4. Revisit the class and methods, finishing each quick description using the Javadoc markup language. We won't cover all of this markup language, just enough to provide a sense of how the tool is used to make clean, professional API documentation.

5. Run Javadoc to create the documentation. Fix any errors in your comment markup. Also, rework the documentation as necessary to be sure that you've capture important information about the class, the methods, the design decisions.

Generally, Javadoc is part of your Python Itegrated Development Enviromment (IDE). To run Javadoc from the command line, you'll use a command similar to the following.

```
javadoc -classpath junit-4.4.jar:. -d doc Card.java TestCard.java
```

The `-classpath` option provides all of the additional `.jar` files that are required to interpret the classes. The `-d` option defines the directory to which the documentation is written. The arguments (in this case, `Card.java` and `TestCard.java`) is a list of package directories or java files to be documented.

Additionally, you can provide a `package-info.java` file in each package directory to create an overall comment for a Java package. This file contains a Javadoc comment block and a **package** statement. You can also create a `doc-files` directory to contain additional documentation outside the Javadoc framework.

## Basic Javadoc Markup

The essential technique for Javadoc is to place documentation comments immediately before class, interface, constructor, method, or field declarations. A documentation comment starts with `/**` and ends with `*/`. They are Java comments with an extra `*`. Javadoc markup is written in HTML. These comments must be placed immediately before the class or method to which they apply.

The first sentence is captured separately as a summary, and must be carefully written to be pithy and useful. Here's an example of a class comment.

```
/**
A single playing card, suitable for Blackjack or
    Poker.  While a suit is retained, it doesn't figure into
    the ordering of cards, as it would in Bridge.

<p><b>Note</b>. The internal rank of an Ace is 14.  The constructor,
    however, expects a value of 1.</p>
*/
public class Card {
...
}
```

❶ The comment begins with `/**` and is immediately in front of the class. The comment begins with a pithy summary of what the class does.

❷ HTML can be used freely within the documentation.

## Javadoc Tags

Javadoc tags are primarily used to tie your documentation directly to Java language structures. Each tag is a separate paragraph that starts with `@` and a tag. We won't cover all of the tags, just enough to produce basic documentation.

The tags also provide several standard kinds of standard "formal paragraphs" within your document. We'll look at these separately.

**Methods.** The following tags are used to define detailed features of a method.

- `@param p` *`some text`*

  This tag defines a positional parameter, `p`.

- `@return` *`some text`*

  This tag defines the return value from the method.

Here's an example of a method comment that uses `@param` tags.

```
    /**
    Creates a new card with a given rank and suit.
    @param rank rank, from 1 to 13
    @param suit one character suit: Card.Clubs, Card.Diamonds,
    Card.Hearts, Card.Spades
    */
    public Card( int rank, String suit ) {
        this.rank= rank;
        if( rank == 1 ) {
            this.rank= 14;
        }
        this.suit= suit;
    }
```

**Standard Paragraphs.** There are several kinds of standard paragraphs that are part of any well-written document set. These include things like

- Related Topics. Use the `@see` tag to generate a "See Also" paragaph with references to other documents. Also, a `{@link}` tag generates an in-line reference to another Javadoc section. Note that the `{@link}` tag requires extra punctuation of `{` and `}`.

- Status. You can track the development and deployment status of your programs with tags like `@version`, `@deprecated` and `@since`. To see the `@version` tag, you must use the `-version` option when runnning the Javadoc utility.

- Bibliographic Information. You can provide standard publication information with tags like `@author`.

Here's an example of a class javadoc comment with some standard paragraphs.

```
import junit.framework.TestCase;
/**
Unit test for the {@link Card} class.
@see Card
@version 1.1
*/
public class TestCard extends TestCase {
...
}
```

## Javadoc Example

Here's a quick example of the Card class with javadoc documentation folded in.

**Example E.1. Card.py**

```
import java.text.DecimalFormat;
/** A single playing card, suitable for Blackjack or
    Poker.  While a suit is retained, it doesn't figure into
    the ordering of cards, as it would in Bridge.
    <p><b>Note</b>. The internal rank of an Ace is 14.  The constructor,
    however, expects a value of 1.
*/
public class Card {
    /** The Card's rank.  Ace is represented as 14 */
    public int rank;
    /** The Card's suit.  Each suit is a 1 character string */
    public String suit;
    public static final String Clubs= "C";
    public static final String Diamonds= "D";
    public static final String Hearts= "H";
    public static final String Spades= "S";
    /**
    Creates a new card with a given rank and suit.
    @param rank: rank, from 1 to 13.
    @param suit: one character suit: Card.Clubs, Card.Diamonds,
    Card.Hearts, Card.Spades.
    */
    public Card( int rank, String suit ) {
        this.rank= rank;
        if( rank == 1 ) {
            this.rank= 14;
        }
        this.suit= suit;
    }
    /**
    Converts this Card to a string.
    @return String with rank and suit
    */
    public String toString() {
        if( this.rank == 14 ) {
            return " A" + this.suit;
        }
        return new DecimalFormat("#0").format( this.rank ) + this.suit;
    }
    /**
    Compares the ranks of this card and another.
    @return &lt;0 if this card is lower rank than the other; &gt;0 if this card is
    higher rank than the other; ==0 if the two cards have the same rank.
    */
    public int compareTo( Card other ) {
        return this.rank - other.rank;
    }
}
```

❶ The class comment. This has some additional HTML markup.

❷ A variable comment.

❸ An example of a method comment.

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## Colophon

The following toolset was used for production of this book.

- Python 2.5.
- Java J2SE 1.4.2 SDK.
- XMLmind XML Editor (XXE) 3.6.1.
- Docbook XSL stylesheets 1.68.1. These had to be extended to correctly format class synopsis in Python.
- Xalan Java 2.4.1.
- FOP 0.20.5. Note that a number of Docbook features aren't handled well by FOP.
- MathCast 0.8.
- The Gimp 2.2.1 with GTK+ 2.4.14
- Mozilla Firefox 2.0.0.14. Primarily to debug CSS's.
- xsltproc was also used