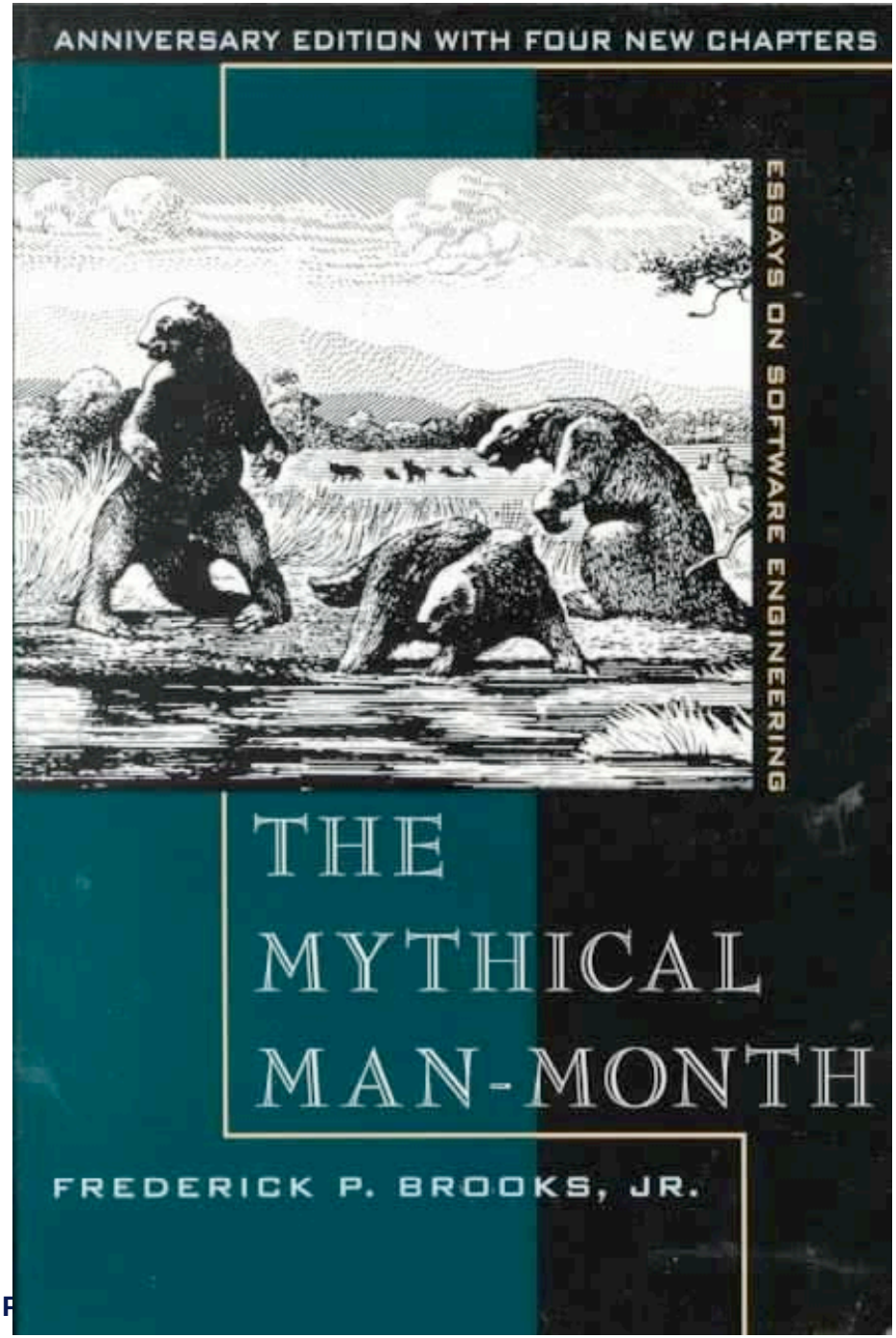
SD2x3.1

Motivating Software Design

Chris

Fred Brooks


ANNIVERSARY EDITION WITH FOUR NEW CHAPTERS
ESSAYS ON SOFTWARE ENGINEERING
THE MYTHICAL MAN-MONTH
FREDERICK P. BROOKS, JR.

Fred Brooks


COMPUTER
No Silver Bullet
Fred Brooks on Avoiding Horrors in the Software Engineering Process

“**There is no single development**, in either technology or in management technique, **that by itself promises even one order-of-magnitude improvement** in productivity, in reliability, in simplicity.”

"I believe the hard part of building software to be the **specification**, **design**, and **testing** of this conceptual construct, not the labor of representing it and testing the fidelity of the representation."

“Essential Difficulties”

- **Complexity:** Too complex for one person to understand
- **Conformity:** Interfaces with different users, systems, etc.
- **Changeability:** Software is “infinitely malleable”
- **Invisibility:** Difficult to diagram or visualize

"Study after study shows that the very best designers produce structures that are **faster, smaller, simpler,** cleaner, and produced with less effort."

“I think the most important single effort we can mount is to develop ways to grow **great designers**.”

What is Software Design?

- The process of converting a set of requirements into a software artifact (code)

- Doing so in such a way that the code is:
  - easy to understand
  - easy to change

Why is Software Design so important?

- Software **changes** during its lifetime
  - Fixing bugs
  - Adding new features
  - Using new libraries
  - Improving efficiency

- Software that is well-designed facilitates those changes, saving time and money

How do we design software?

1. Modeling: identify concepts and their relationships
2. Choose the right architecture
3. Create/Use appropriate data structures
4. Use design patterns when appropriate
5. Refactor (change the design) as necessary

SD2x3.2

Domain Modeling

Chris

How do we design software?

1. Modeling: identify concepts and their relationships
2. Choose the right architecture
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How do we design software?

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How do we design classes?

Domain Modeling

- Identify **concepts** (classes)
- Their **properties** (attributes/fields)
- Their **behaviors** (operations/methods)
- And the **relationships** between them

“Graduate and undergraduate students may apply to the program. The application consists of a recommendation letter and personal statement.”

Grammatical Parsing

- Assign roles based on parts of speech
- **Noun:** class or attribute
- **Adjective:** attribute or subclass
- **Verb:** operation

"Graduate and undergraduate students may apply to the program. The application consists of a recommendation letter and personal statement."

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“Graduate and undergraduate students may apply to the program. The application consists of a recommendation letter and personal statement.”

Grammatical Parsing

- **Nouns:**
  - Students
  - Program
  - Application
  - Letter
  - Statement
- **Adjectives:**
  - Graduate
  - Undergraduate
- **Verbs:**
  - Apply
  - Consists

Nouns: Classes or Attributes?

- A noun should be a **class** if:
  - it has multiple attributes and/or operations
  - all attributes/operations are common to all instances of the class

- Otherwise it should likely be an **attribute** of another class

Adjectives: Attributes or Subclasses?

- An adjective should represent a **subclass** of another class if:
  - different adjectives would imply different or additional operations or behavior
  - different adjectives would imply different attributes

- Otherwise, an adjective should be an **attribute** of a class

Verbs: in which class do they belong?

- "Student may apply to the program"
  - Subject: student
  - Direct object: program

→ "apply" operation should go in Student class

- Certain verbs are more indicative of **relationships** between classes than they are of operations: contains, has, is, uses, consists

Our design

- Class: Student
  - Attributes/Subclasses: Graduate; Undergraduate
  - Operations: Apply

- Class: Letter
- Class: Statement
- Class: Application
- Class: Program

Relationships?

- Graduate Student **is a** Student
- Undergraduate Student **is a** Student

- Application **consists of** Letter and Statement

- Student **uses** Application

- Student is **associated with** Program

Recap: Domain Modeling

- Identify concepts, properties, behaviors, and relationships

- Use **grammatical parsing** to assign roles based on parts of speech
  - **Noun:** class or attribute
  - **Adjective:** attribute or subclass
  - **Verb:** operation

SD2x3.3

UML Class Diagrams

Chris

How do we represent a class design?

“Graduate and undergraduate students may apply to the program. The application consists of a recommendation letter and personal statement.”

"Graduate and undergraduate students may apply to the program. The application consists of a recommendation letter and personal statement."

Relationships

- Graduate Student **is a** Student
- Undergraduate Student **is a** Student

- Application **consists of** Letter and Statement

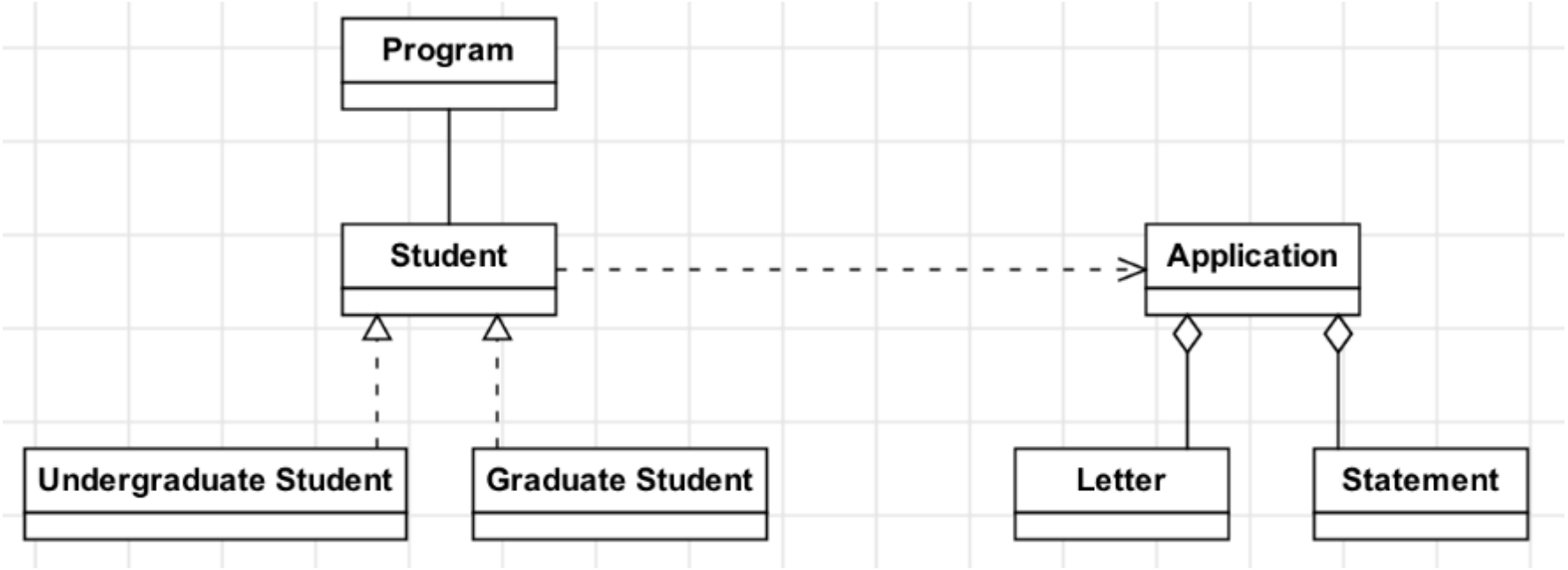
- Student **uses** Application

- Student is **associated with** Program

UML: Unified Modeling Language

- General-purpose language for modeling/visualizing software architecture and design
- Adopted as standard by Object Management Group (OMG) in 1997 and International Standards Organization (ISO) in 2005
- Types of diagrams:
  - Structural
  - Behavioral

UML Class Diagram (Compact)



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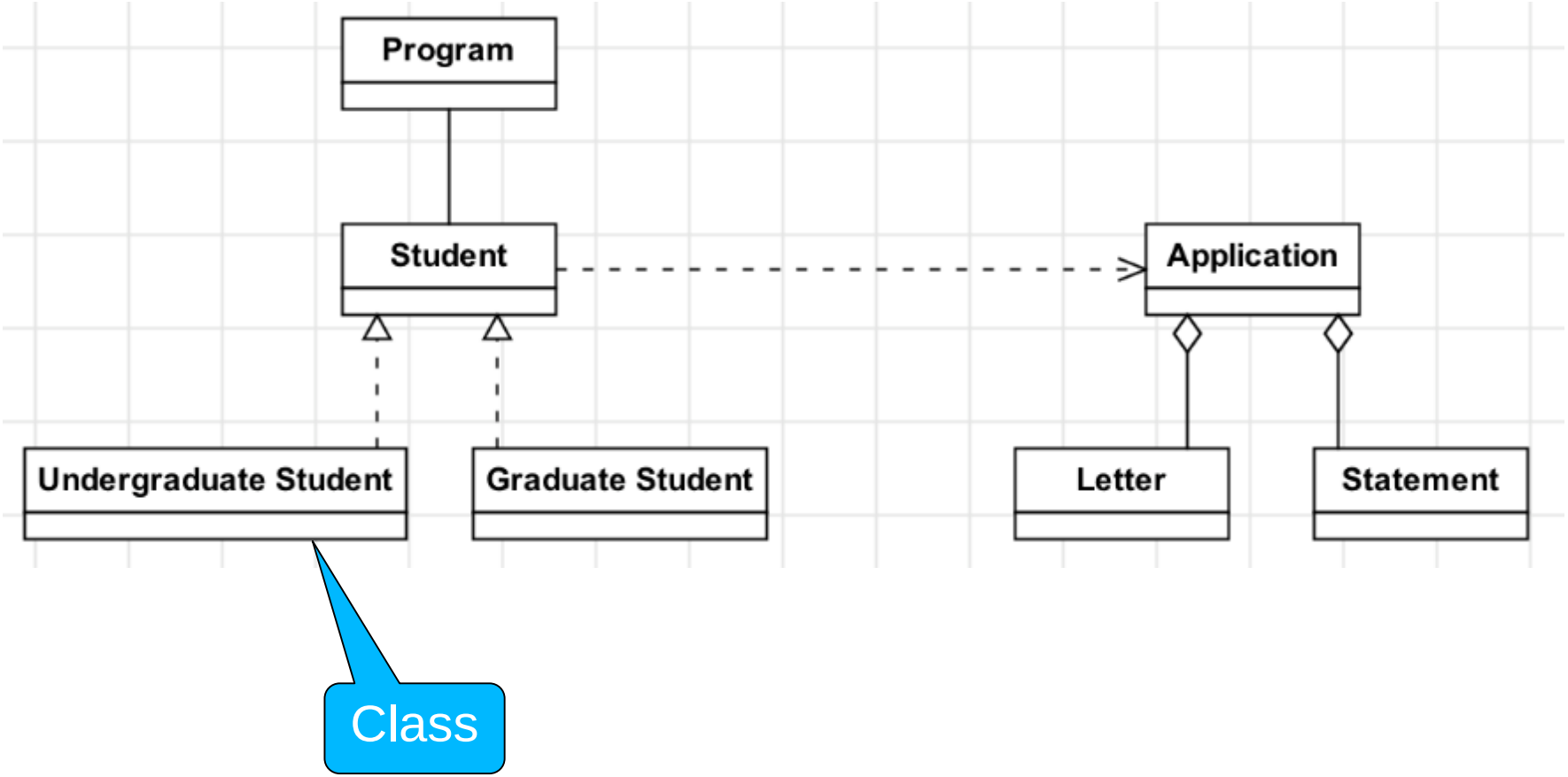
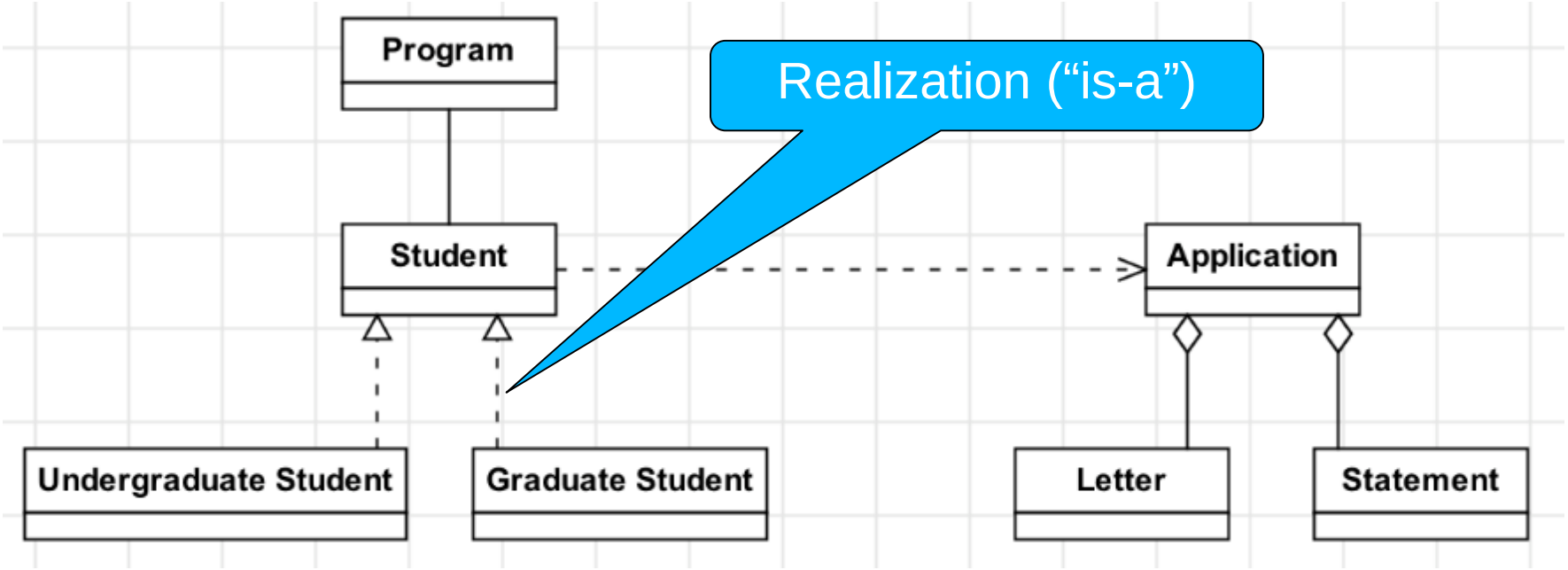
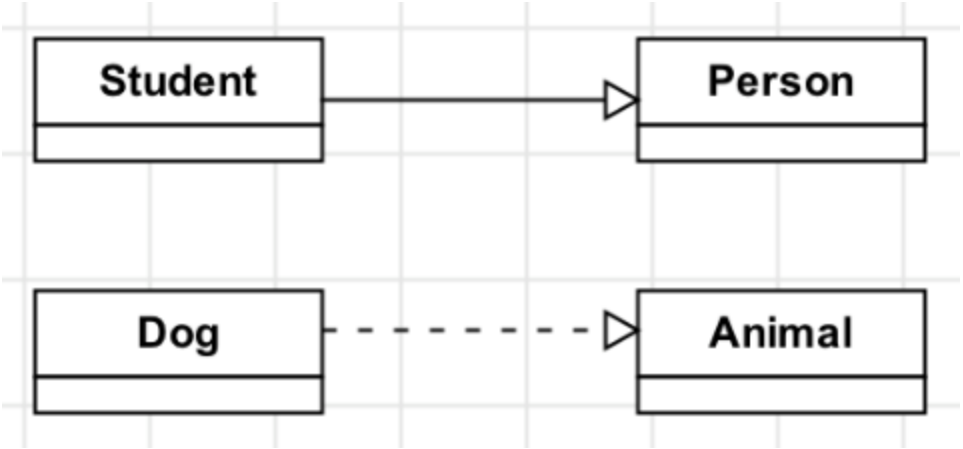


UML Class Diagram



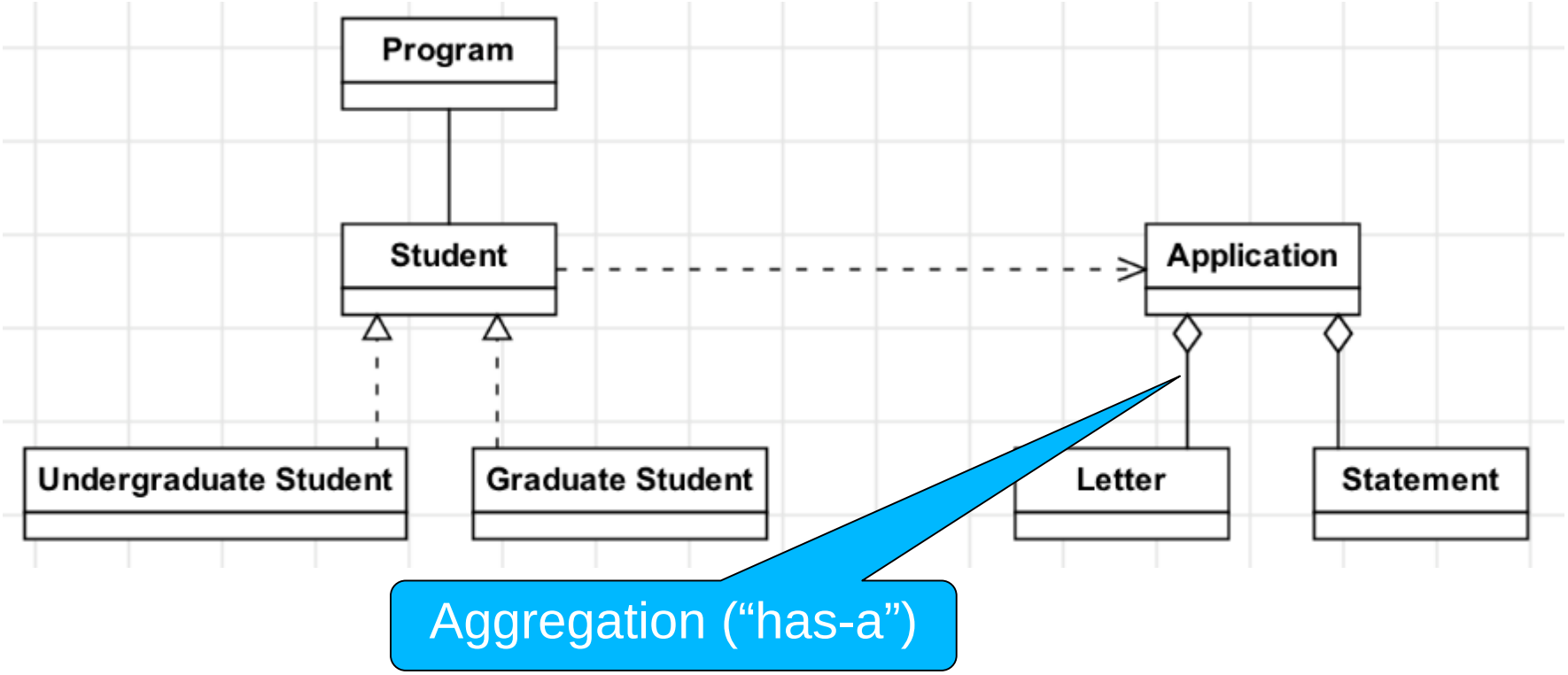
“is-a” Relationships in UML

- **Generalization:** one is a specialized form of the other and provides additional behavior/attributes
- **Realization:** one is the realization/actualization of the model that the other supplies



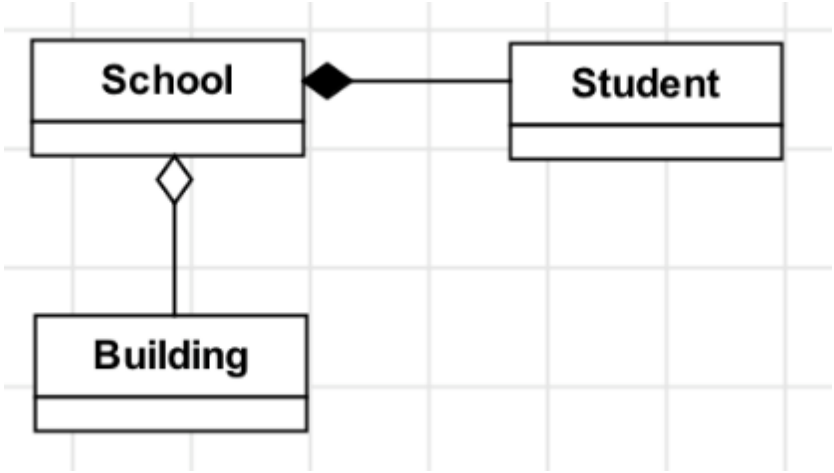
- In Java:
  - Generalization = “extends” a (concrete) class
  - Realization = “implements” an interface

UML Class Diagram



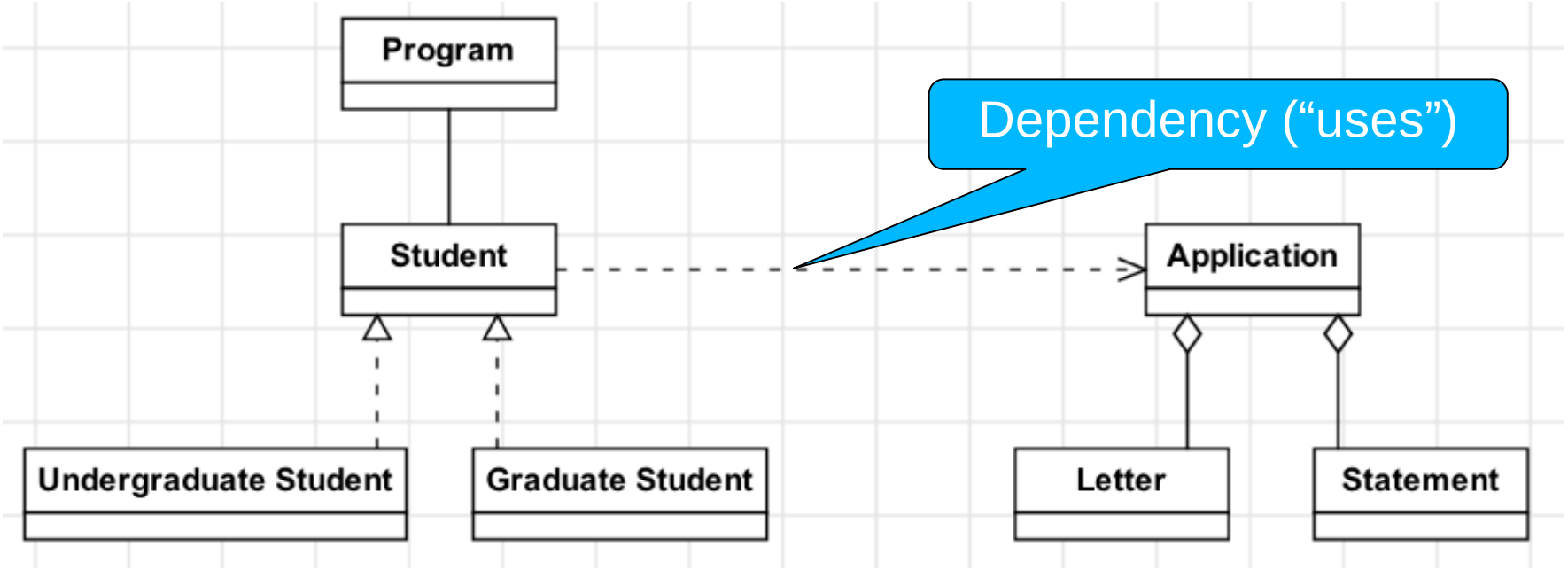
“has-a” Relationships in UML

- **Aggregation:** one class is part of another and can exist independently
- **Composition:** one class is part of another but *cannot* exist independently



- In Java, both are implemented by having one class as a field/attribute of another

UML Class Diagram



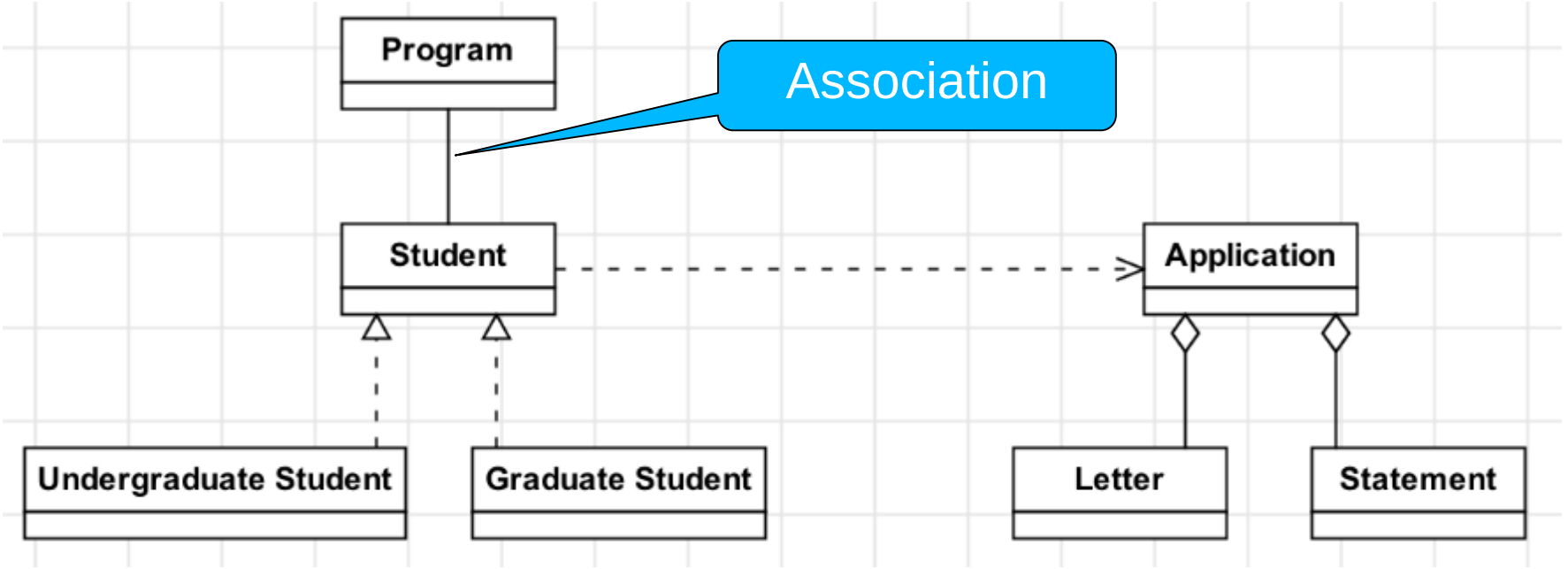
“uses” vs. “has” in UML

- **Dependency (“uses”):** class A uses class B’s operations/attributes but class B is not part of A

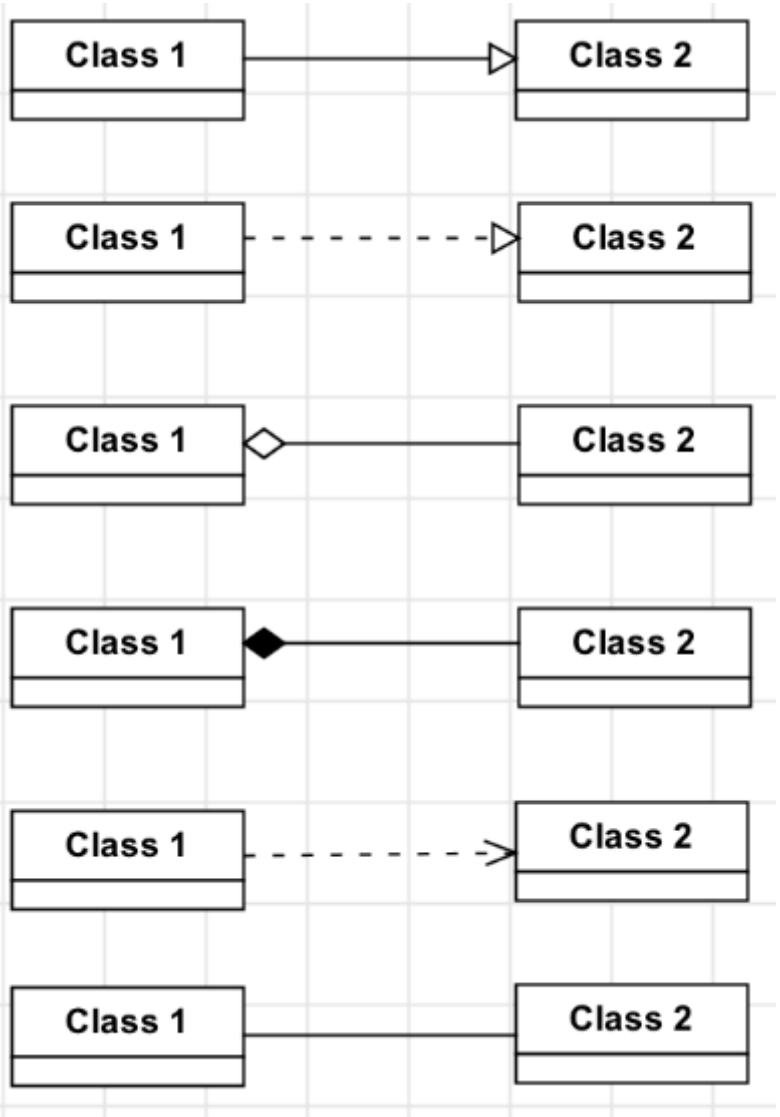
- **Aggregation/Composition (“has”):** class B is part of class A

- In Java, dependency is exhibited when a class is a parameter or local variable in another class, but is not a field

UML Class Diagram



Recap: UML Class Relationships



Generalization

Realization

Aggregation

Composition

Dependency

Association

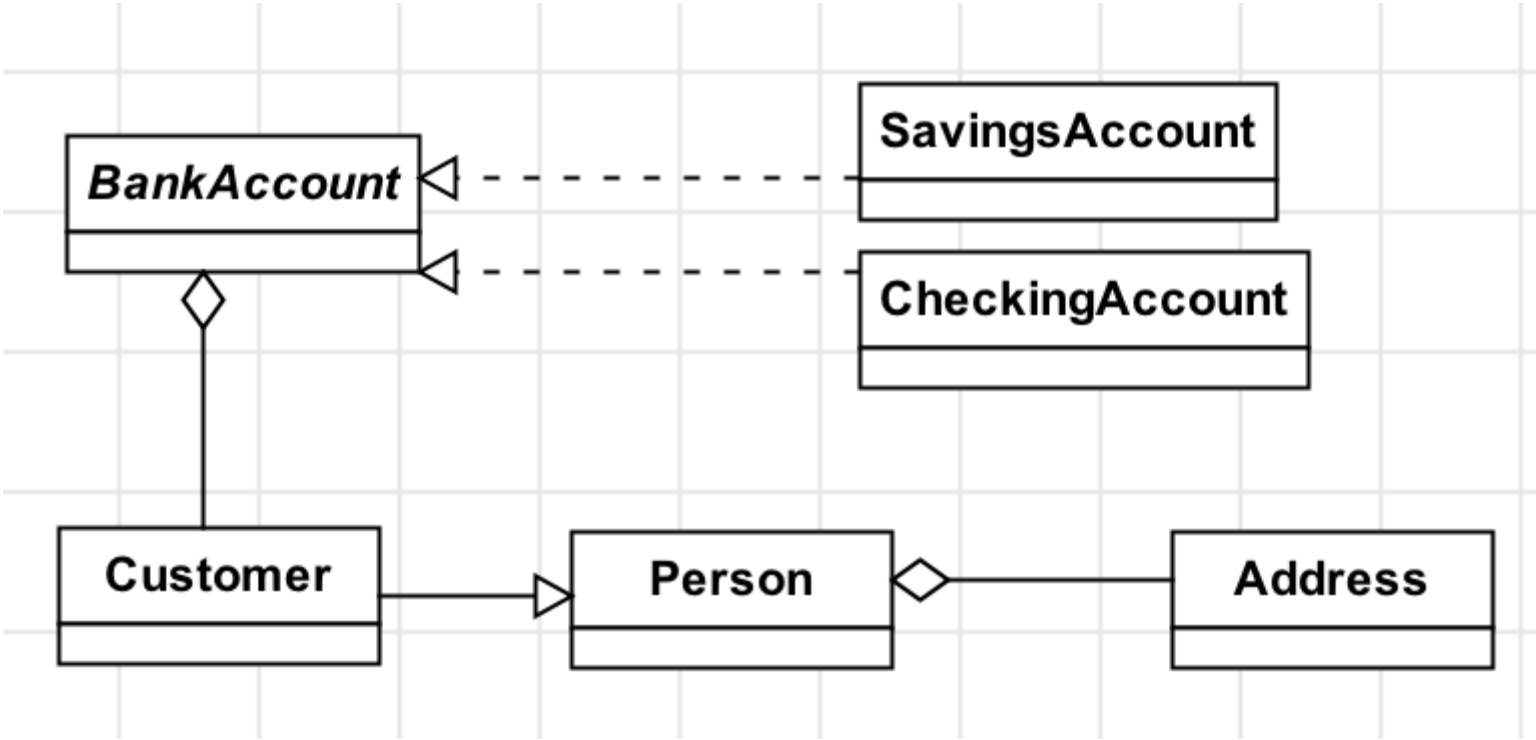
SD2x3.4

Detailed Class Diagrams

Chris

How do we represent more details about a class design?

UML Class Diagram (Compact)



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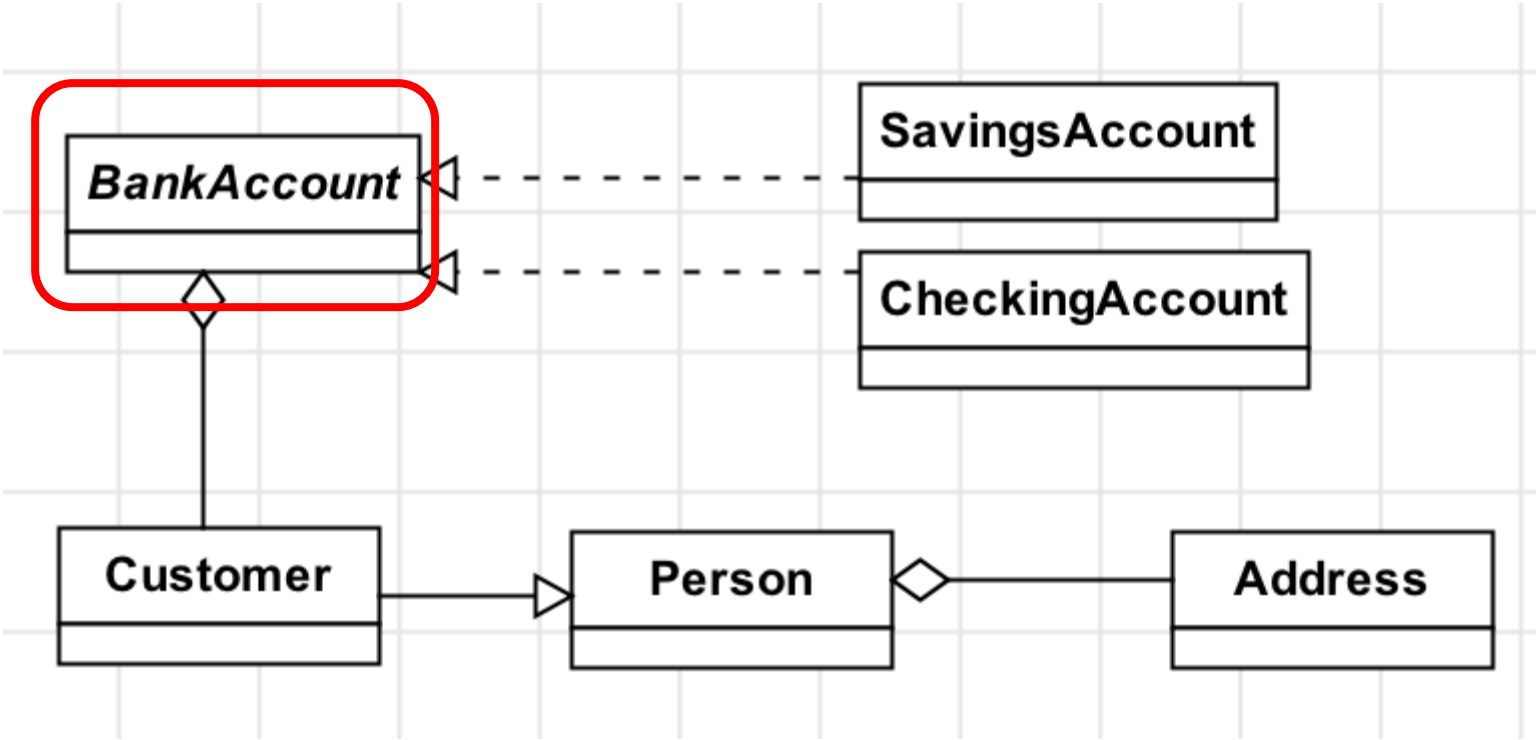

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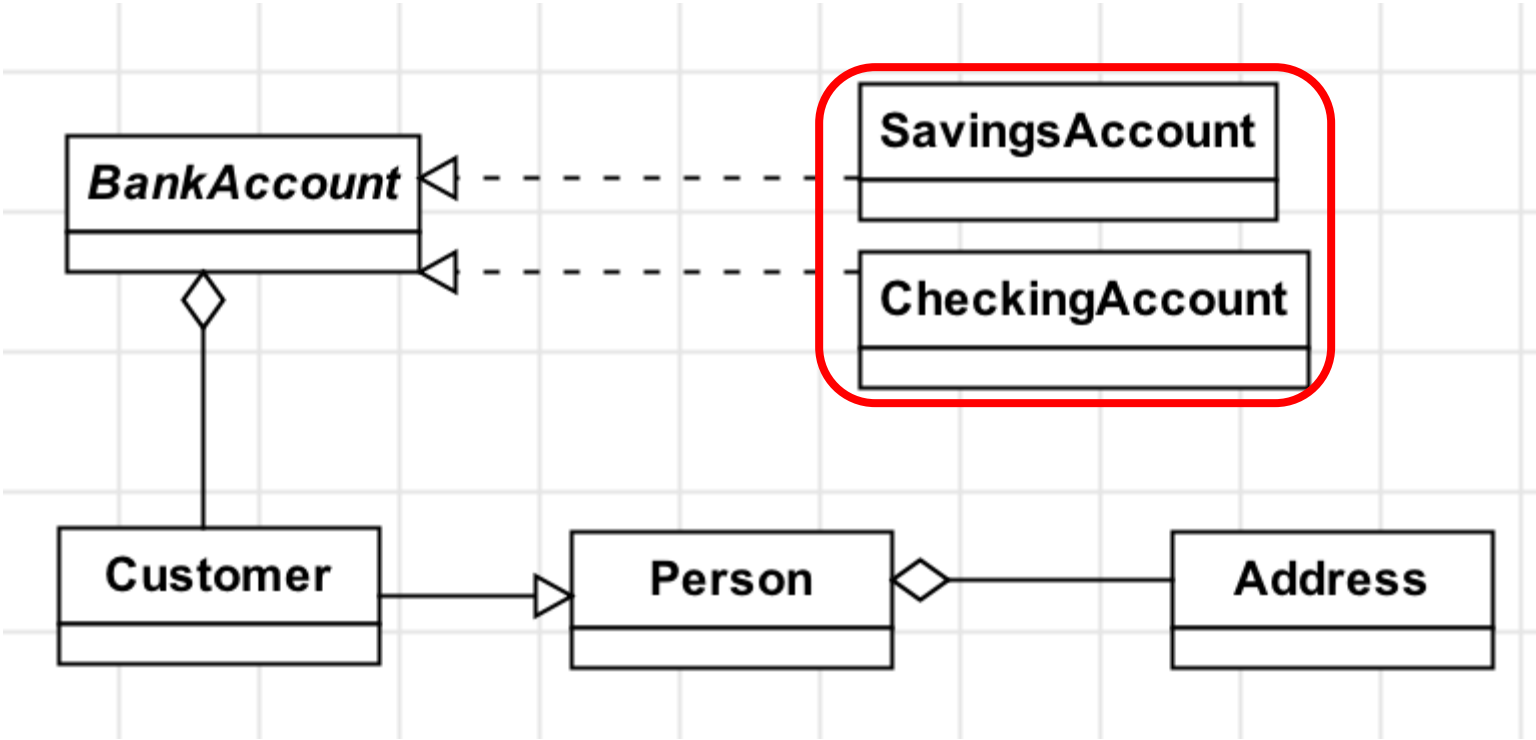

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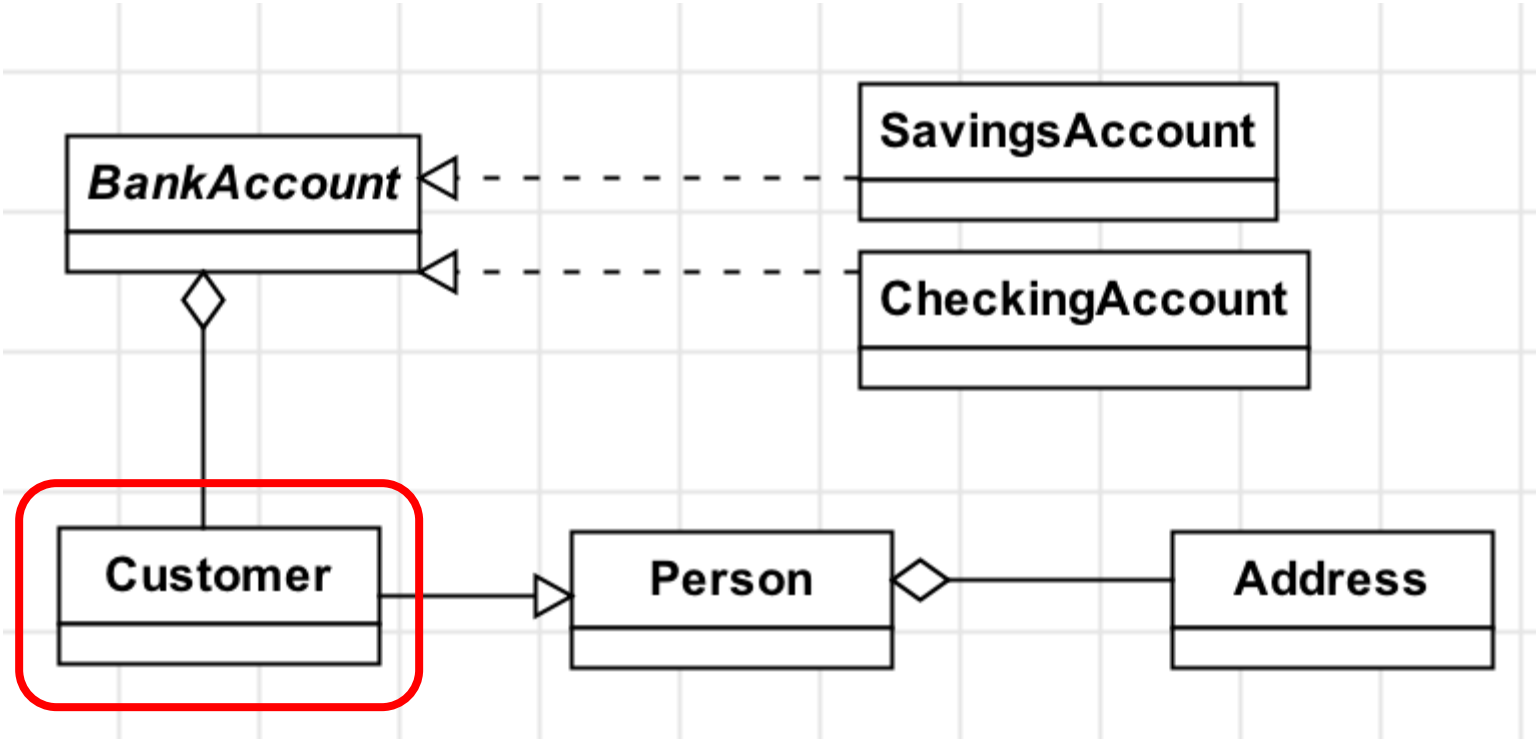

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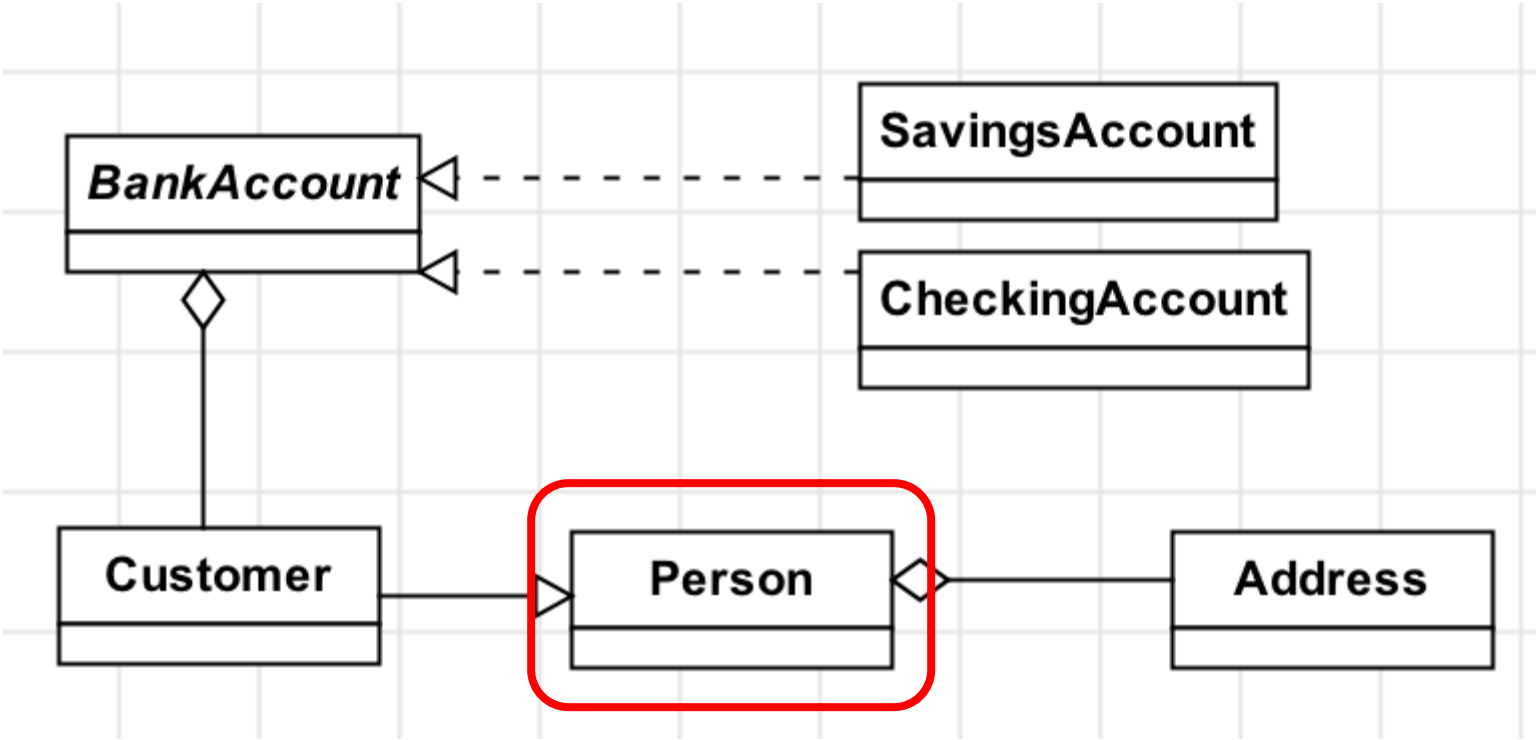

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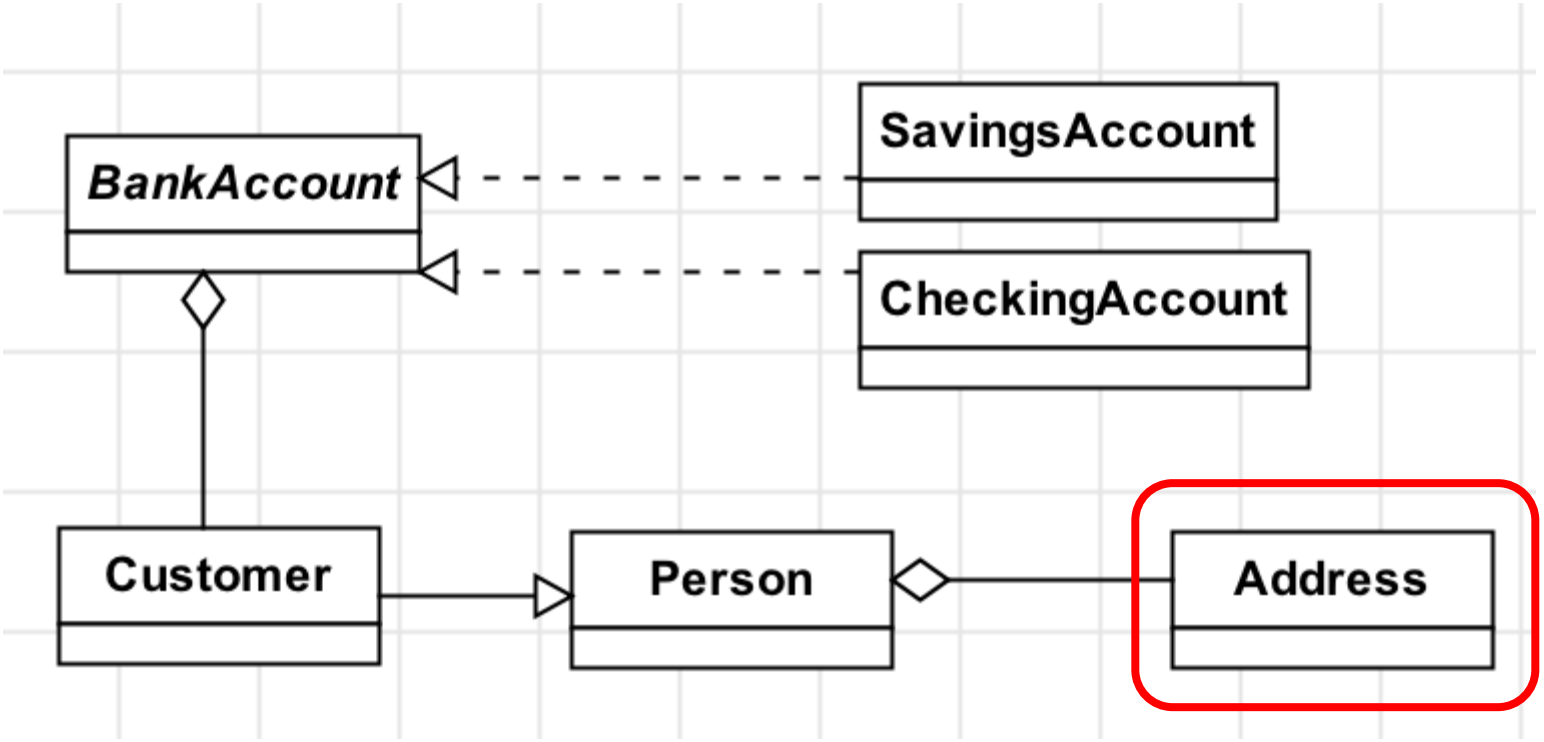

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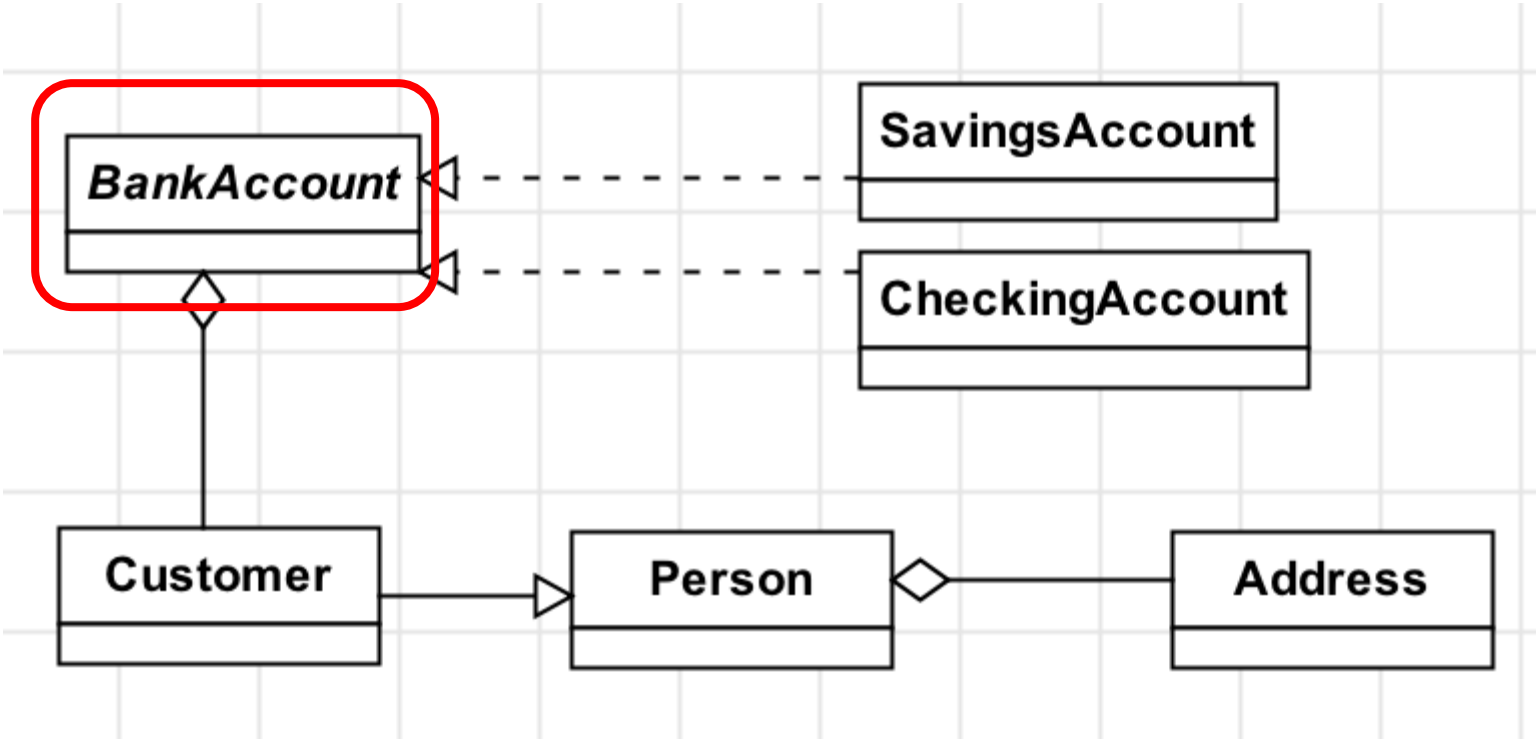

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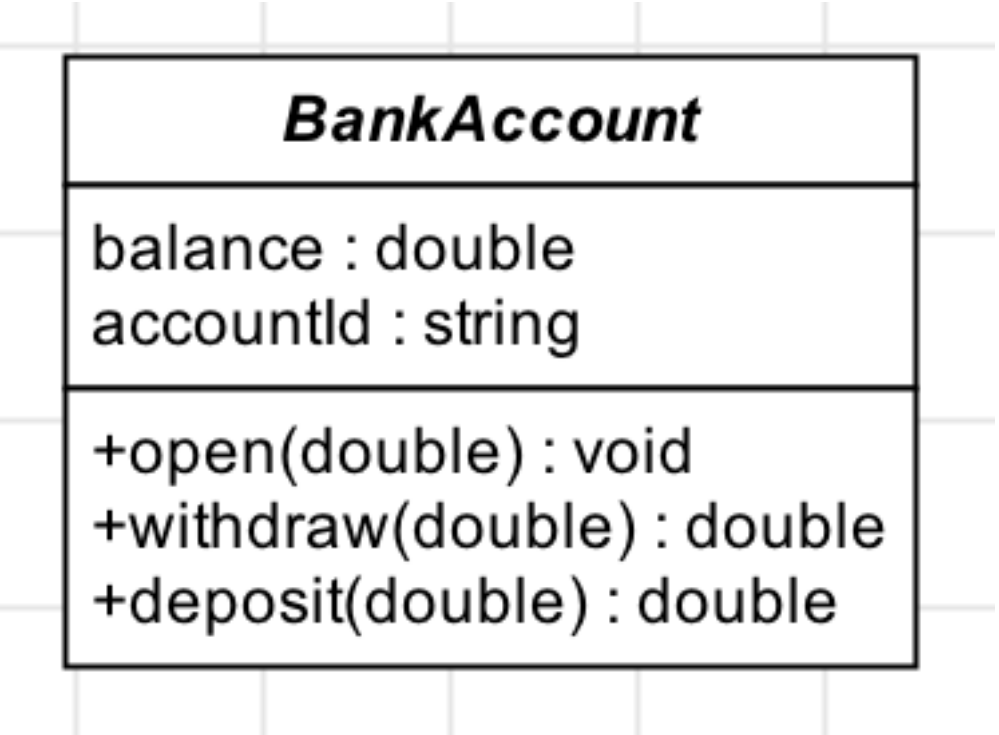

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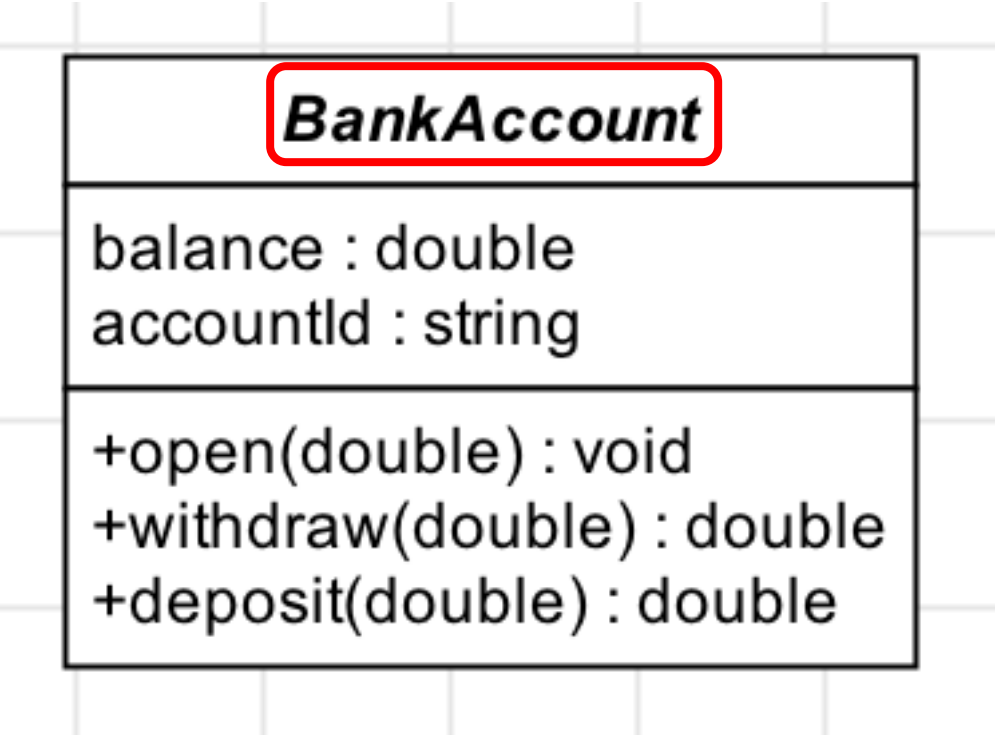

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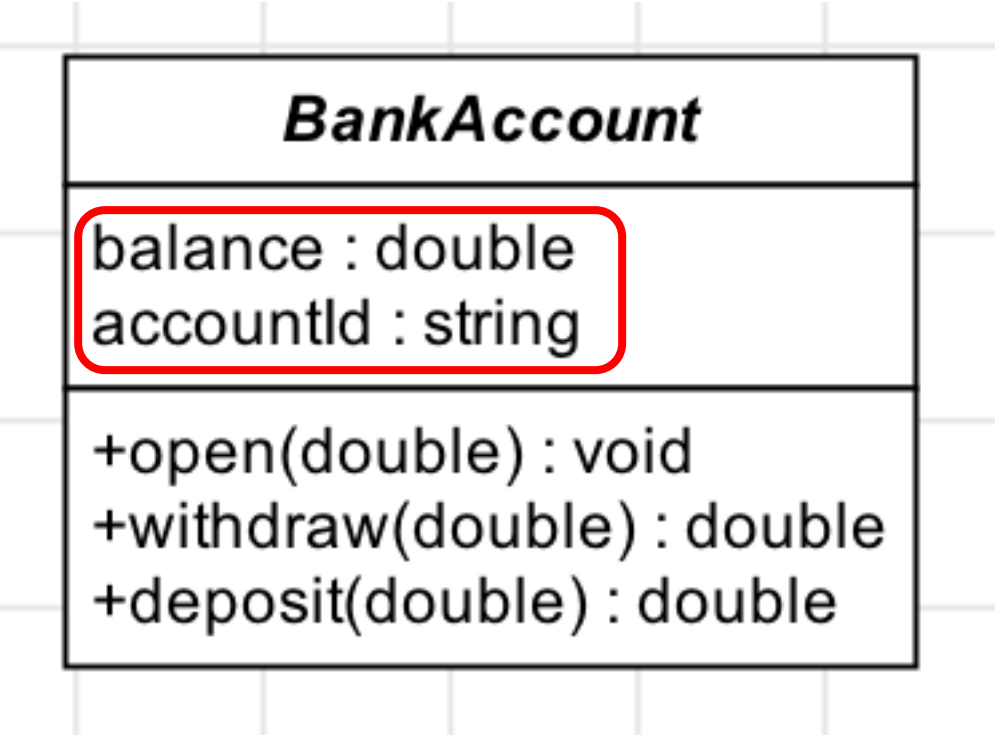

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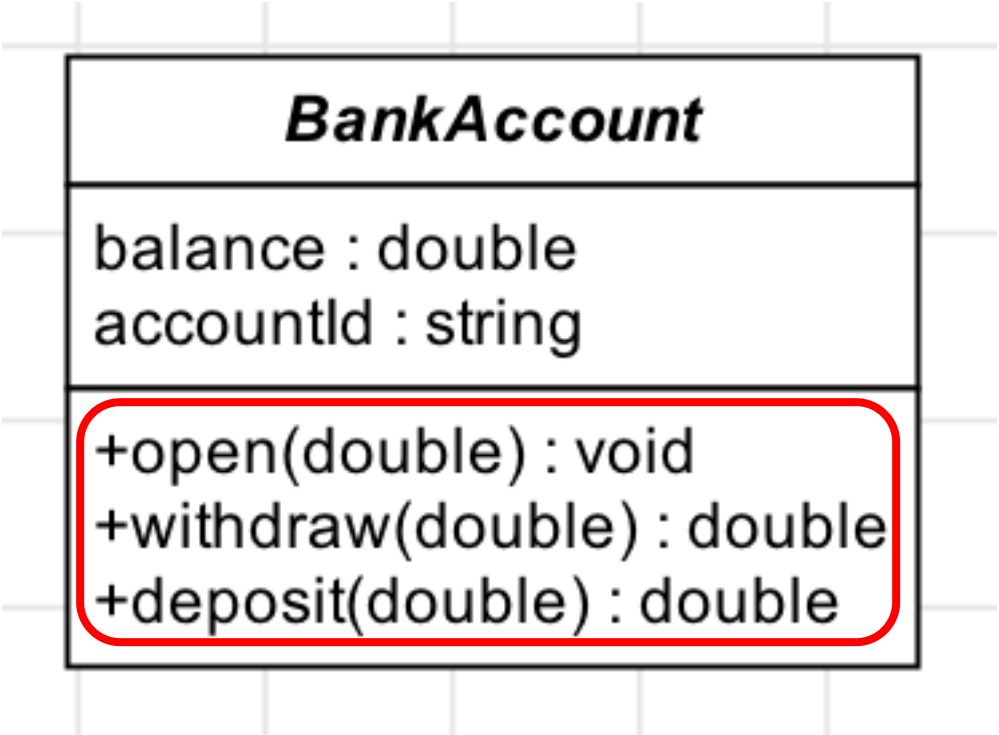

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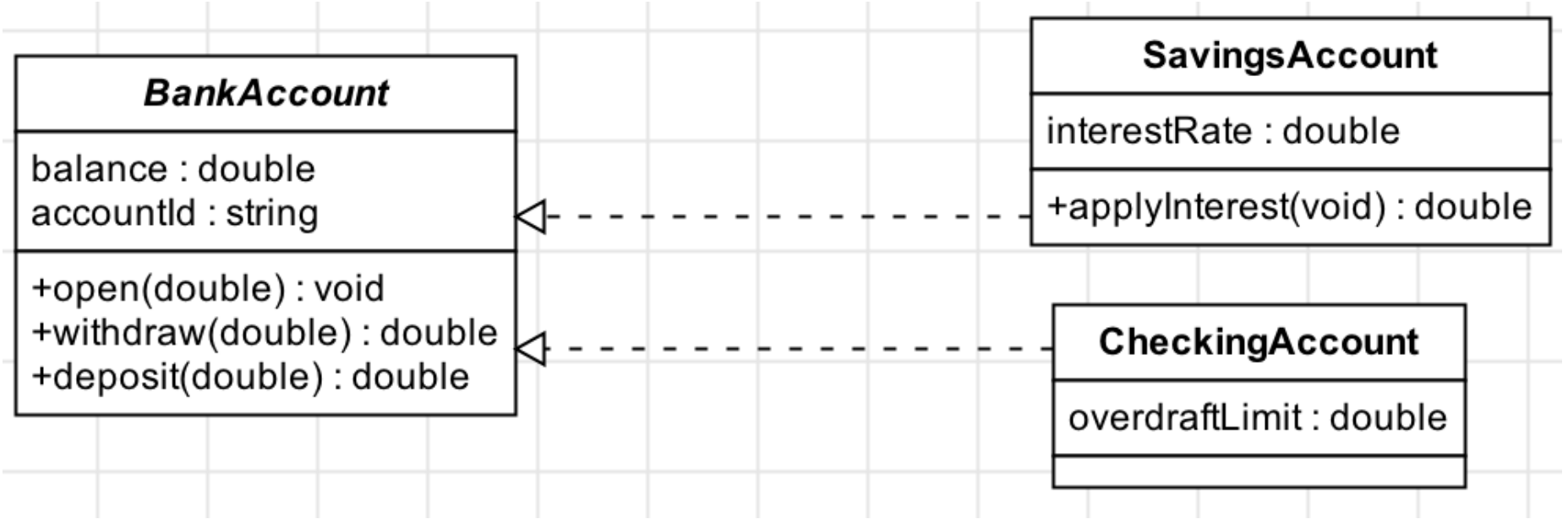

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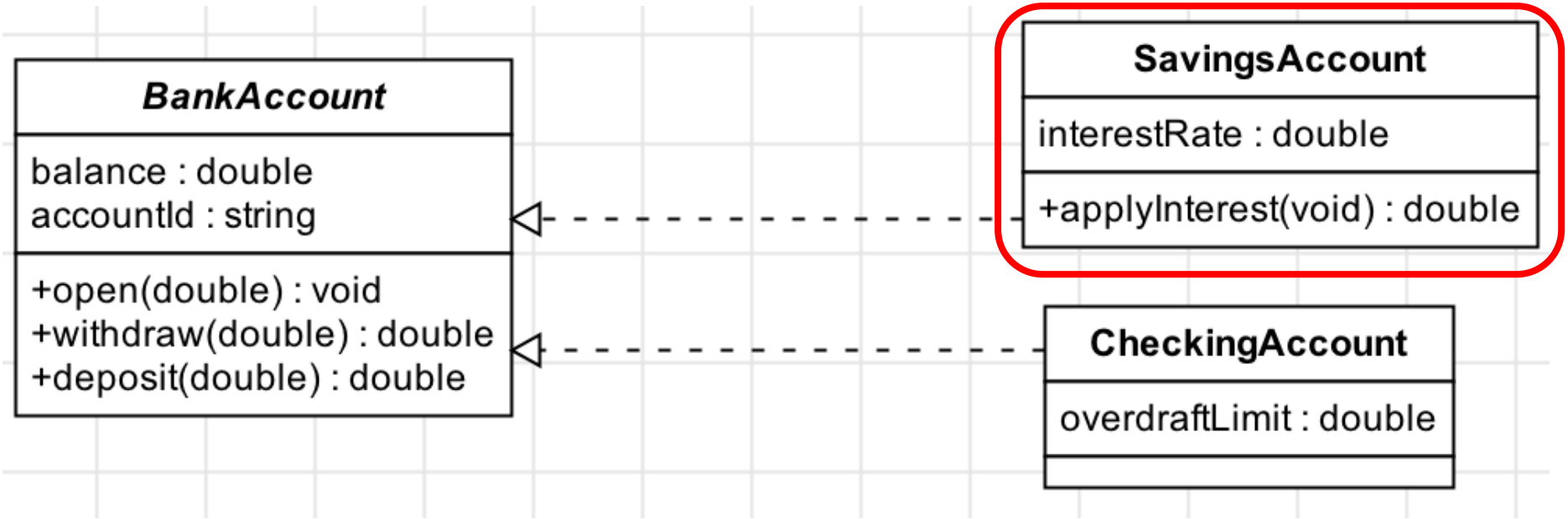

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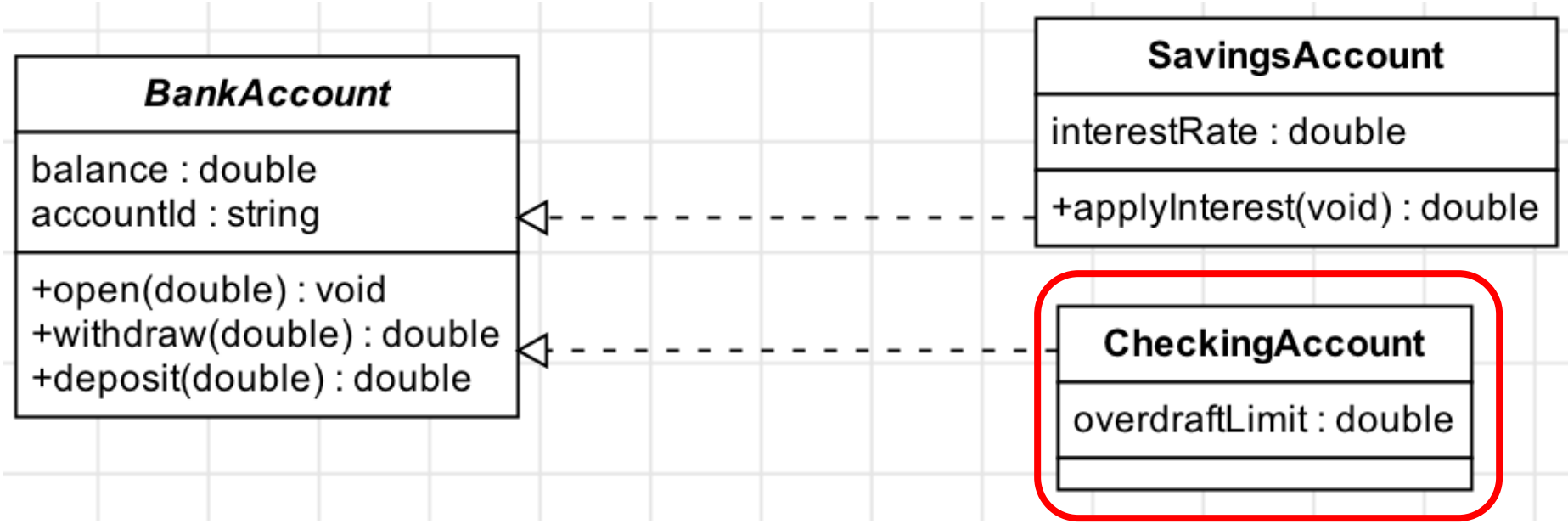

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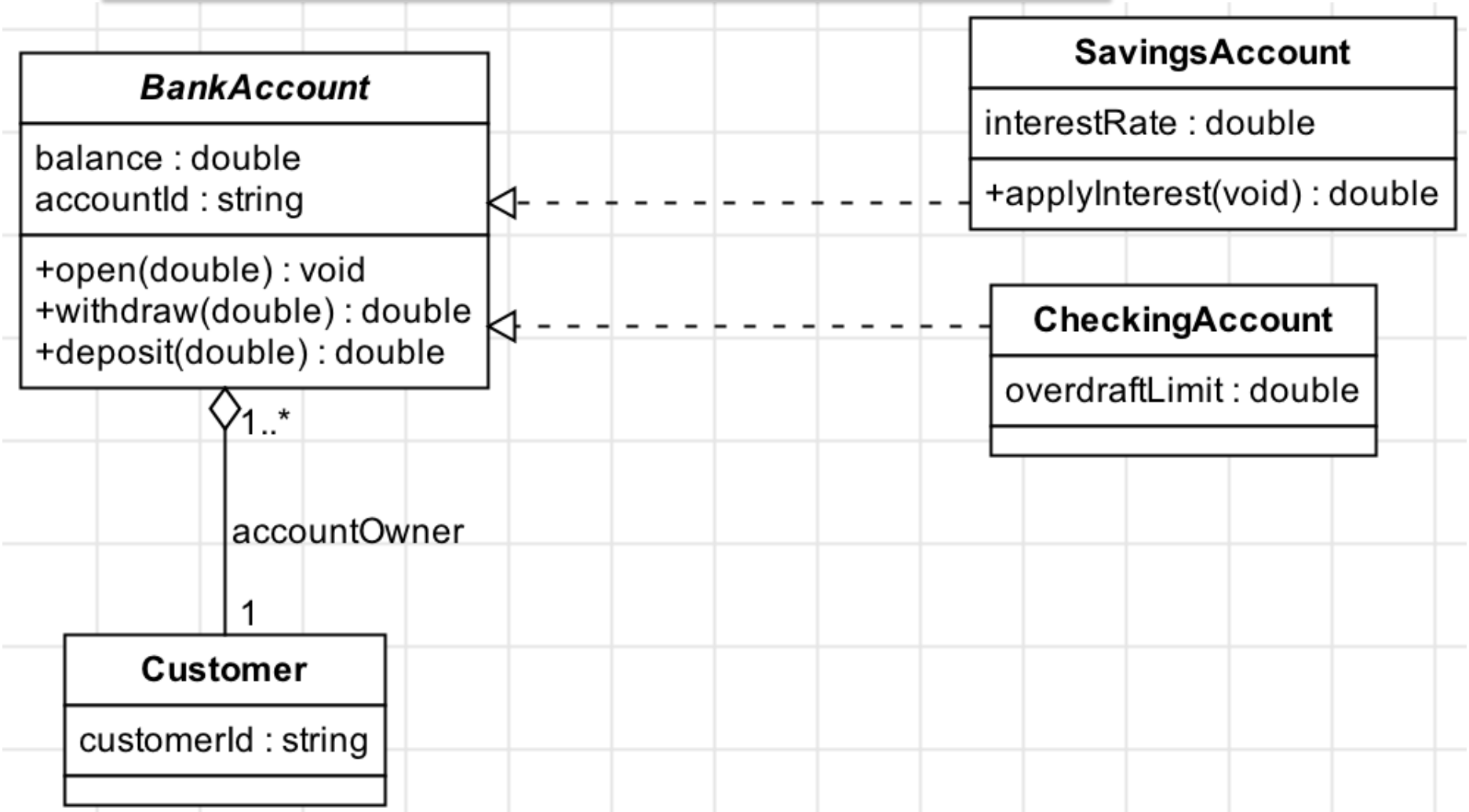

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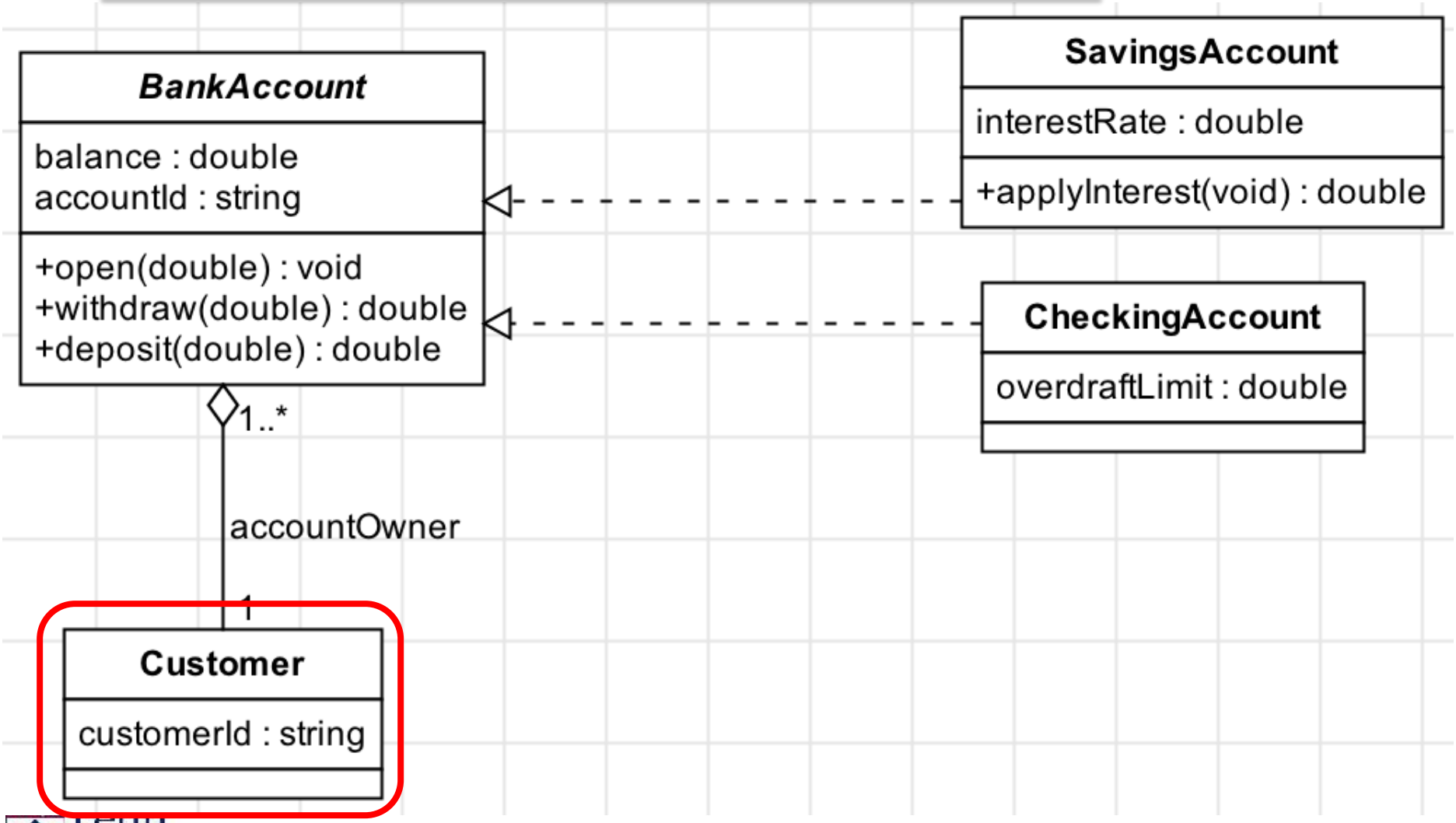

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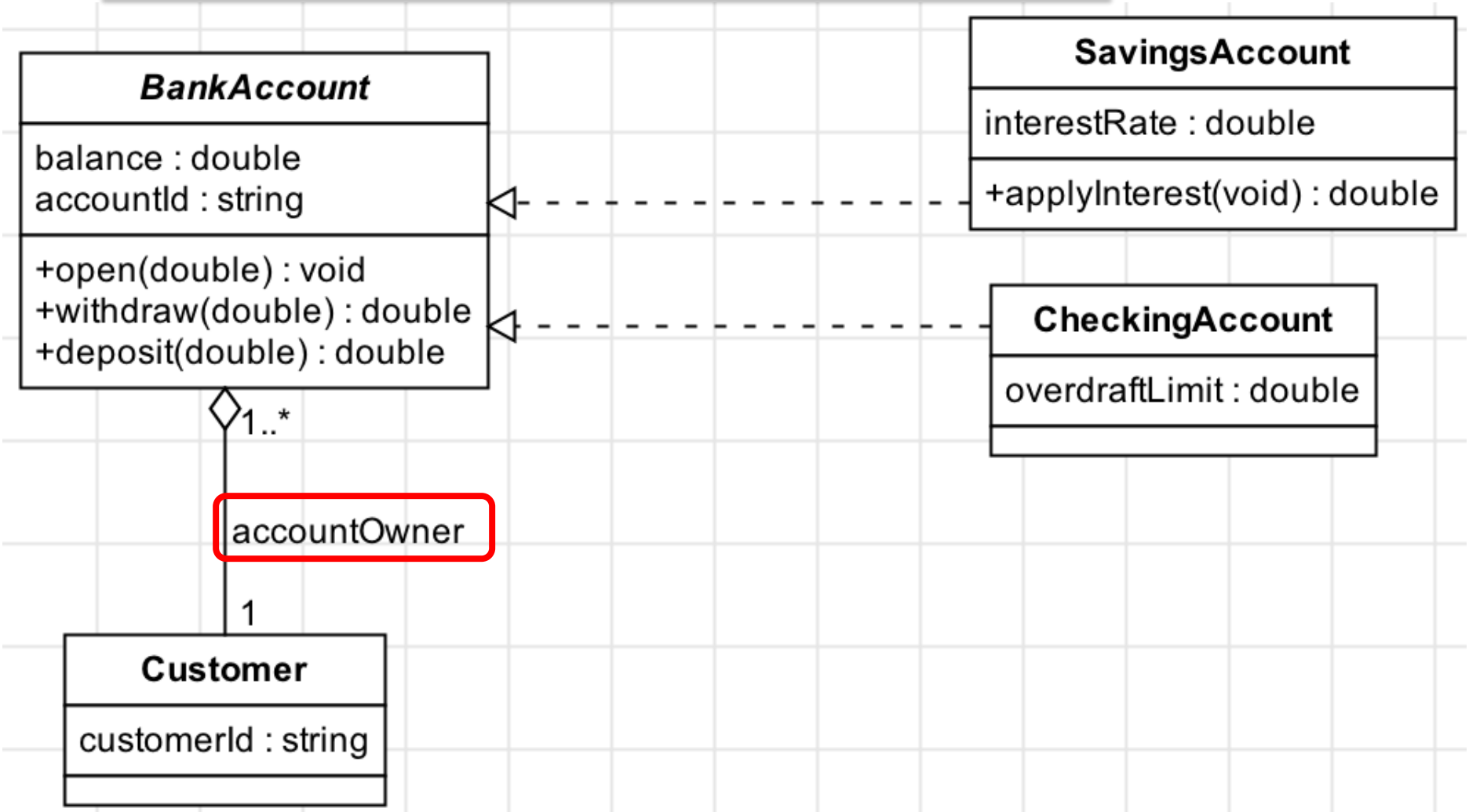

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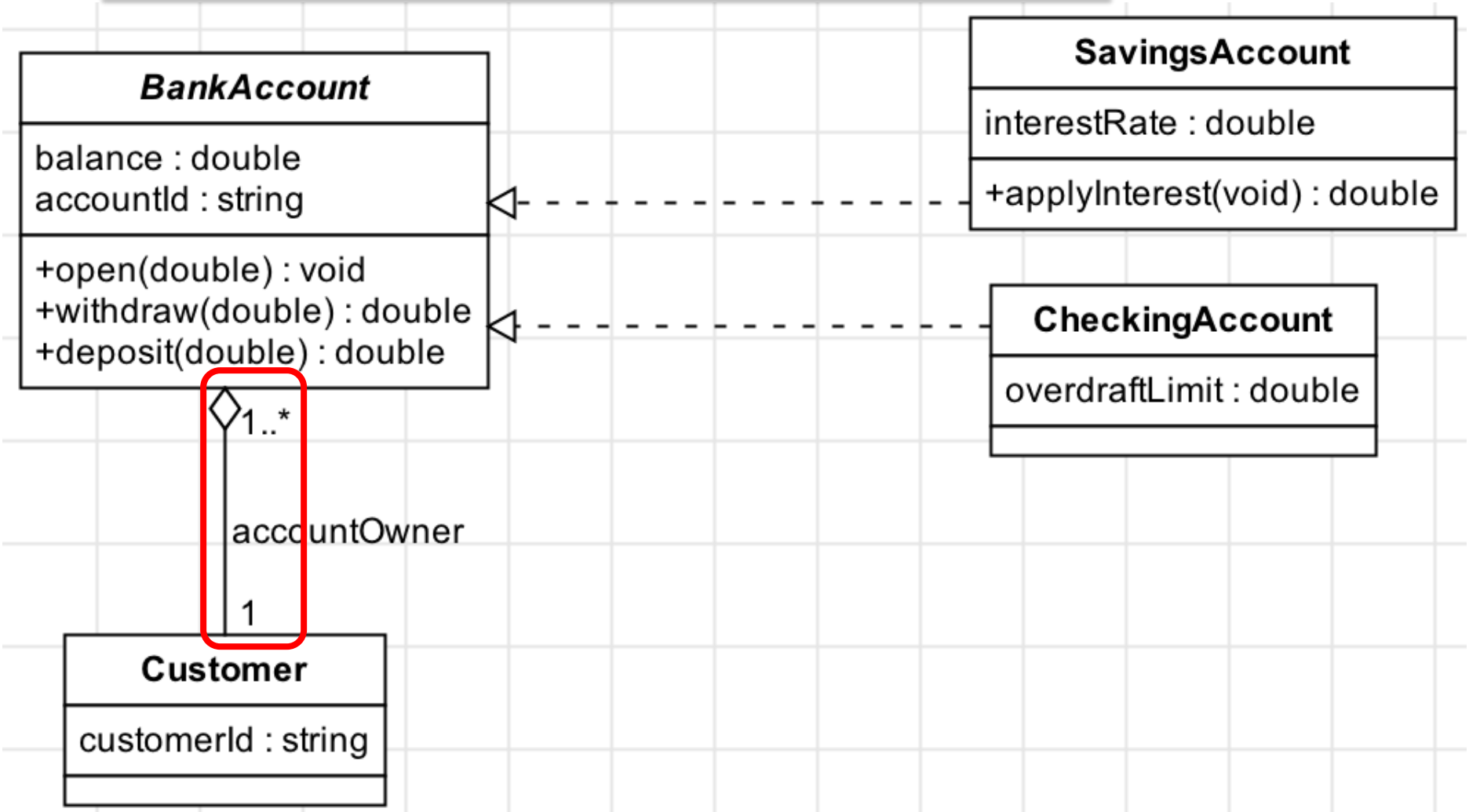
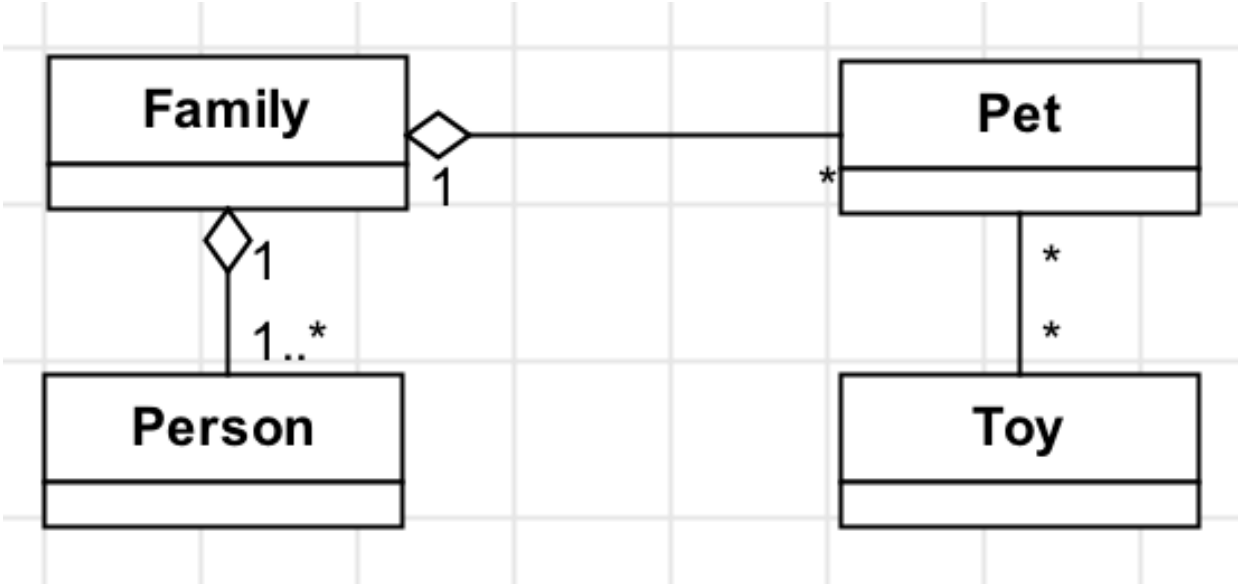


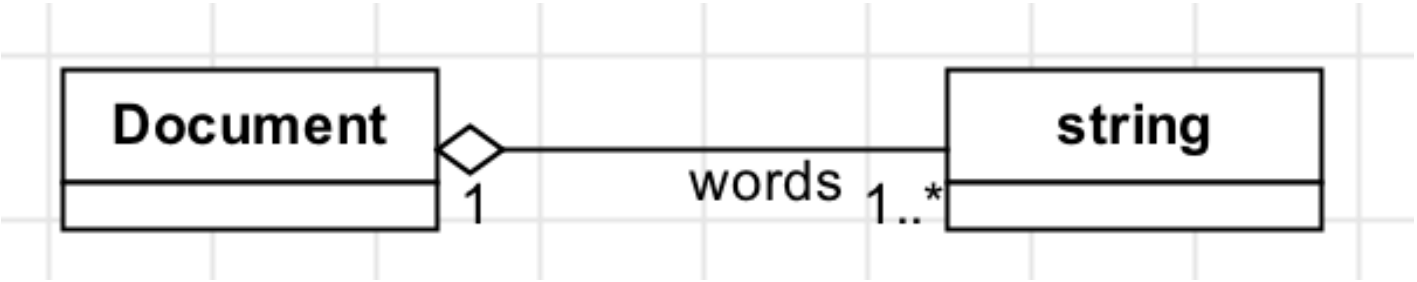
Multiplicity

- Describes the number of objects that can be used in an association
  - *n* : exactly *n* objects
  - * : 0 or more objects
  - *m..n :* a minimum of *m* and a maximum of *n* objects

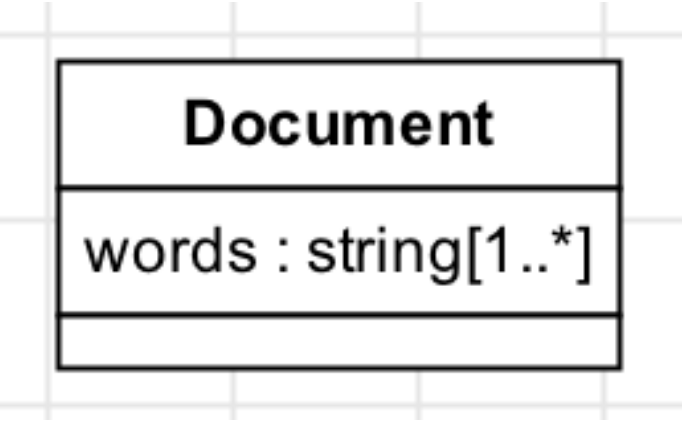


Multiplicity and Attributes

- In general, do not use aggregation/composition for “primitive” types, even to represent multiplicity



- To demonstrate multiplicity, use [ ]-notation



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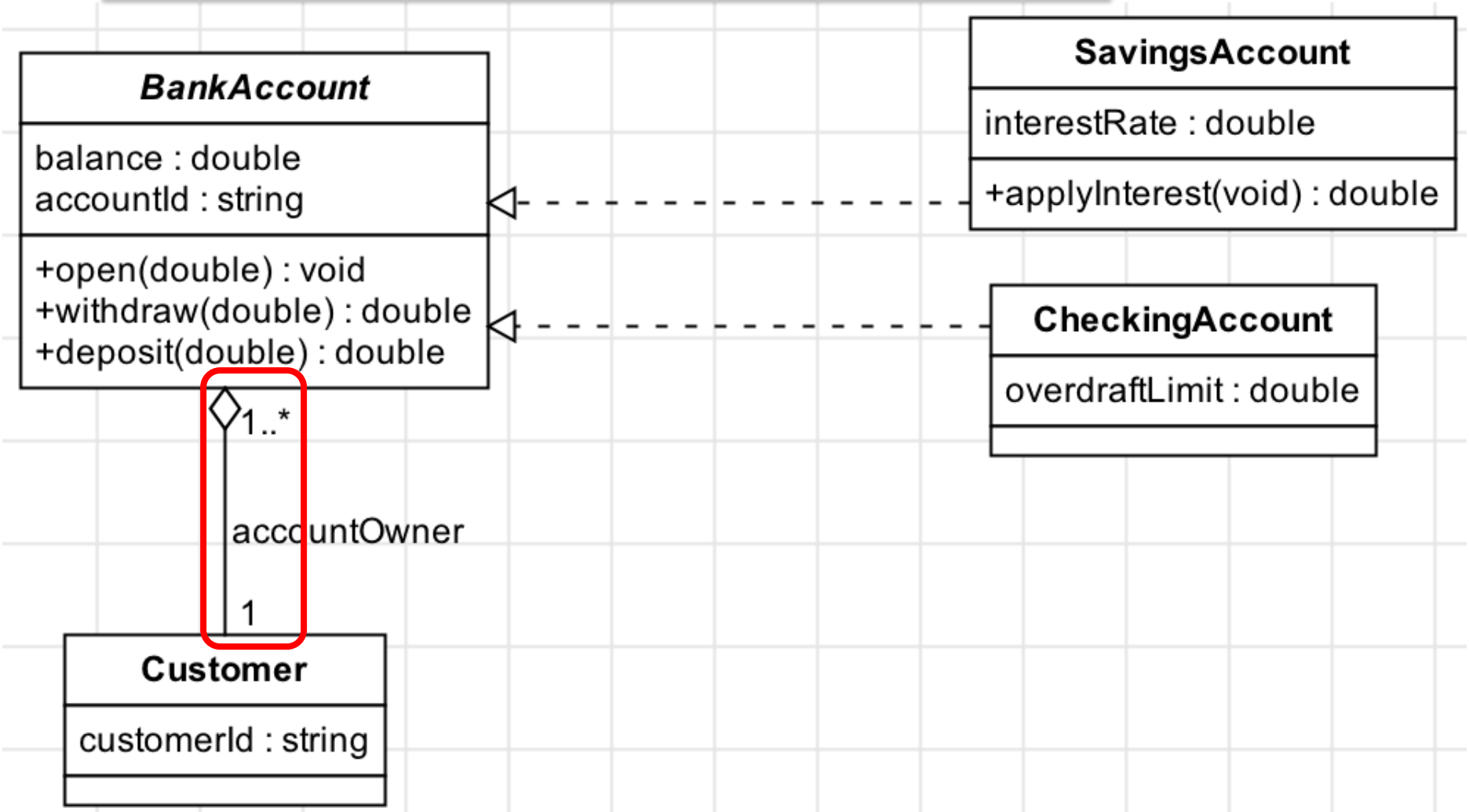

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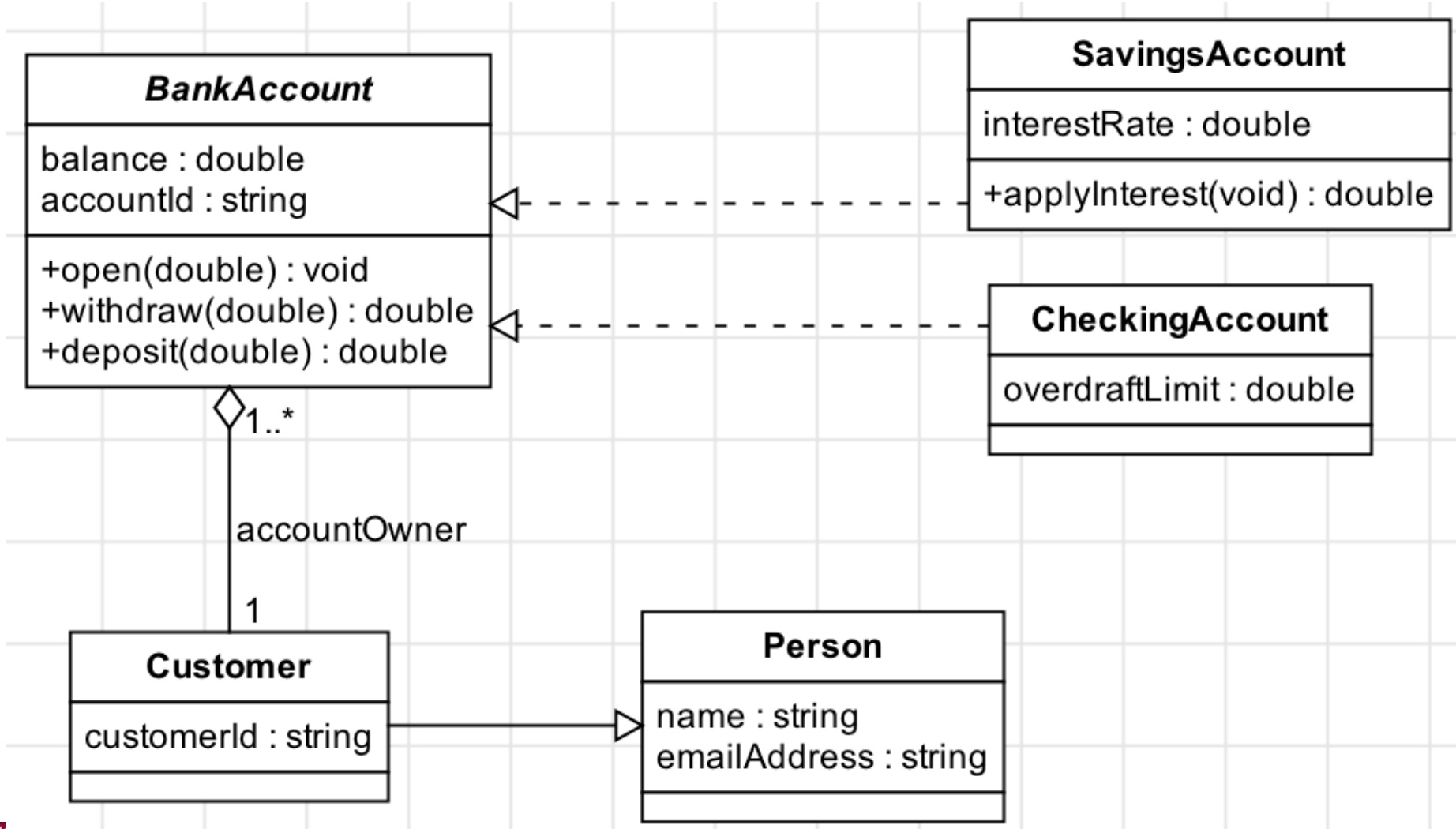

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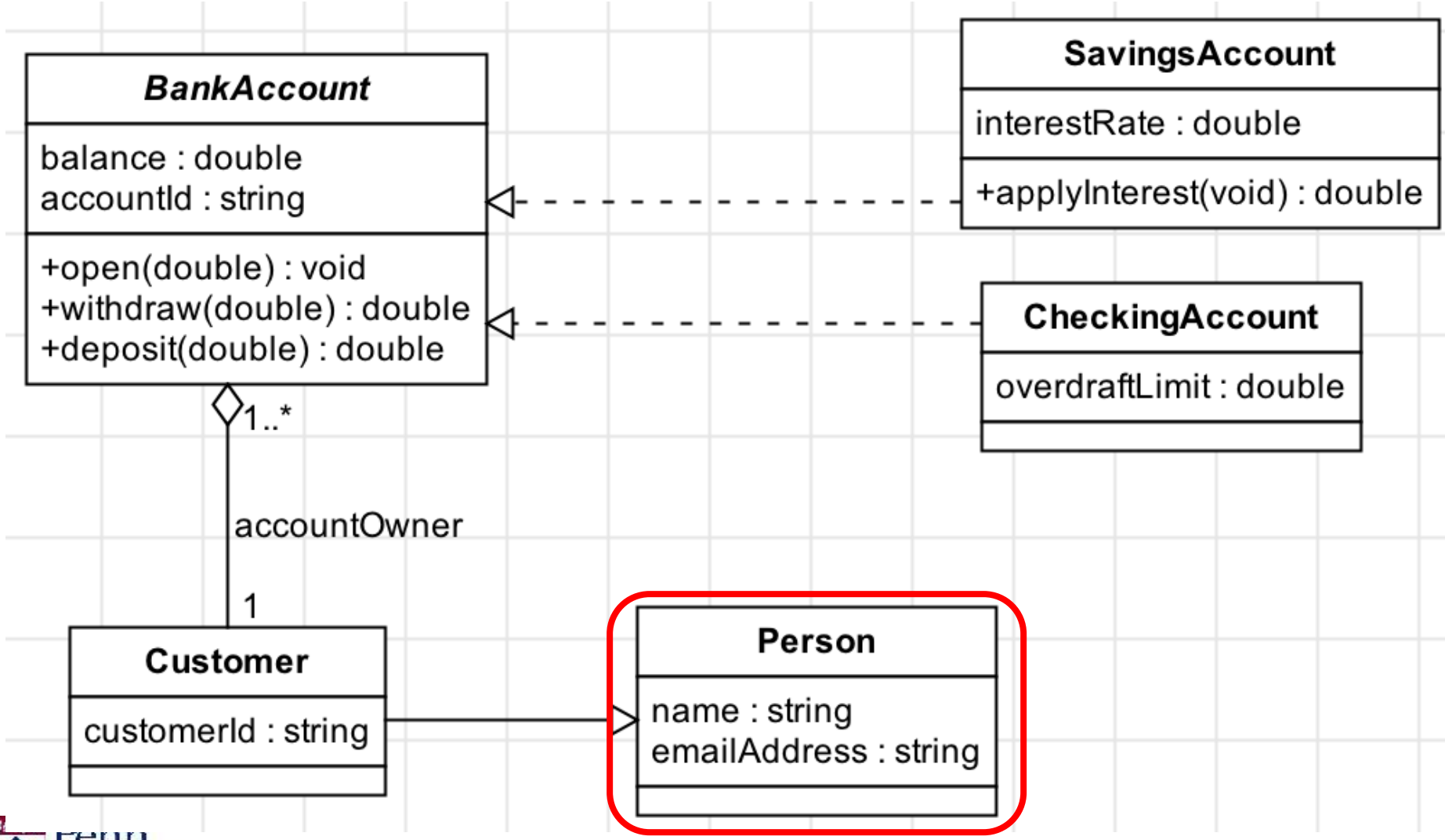

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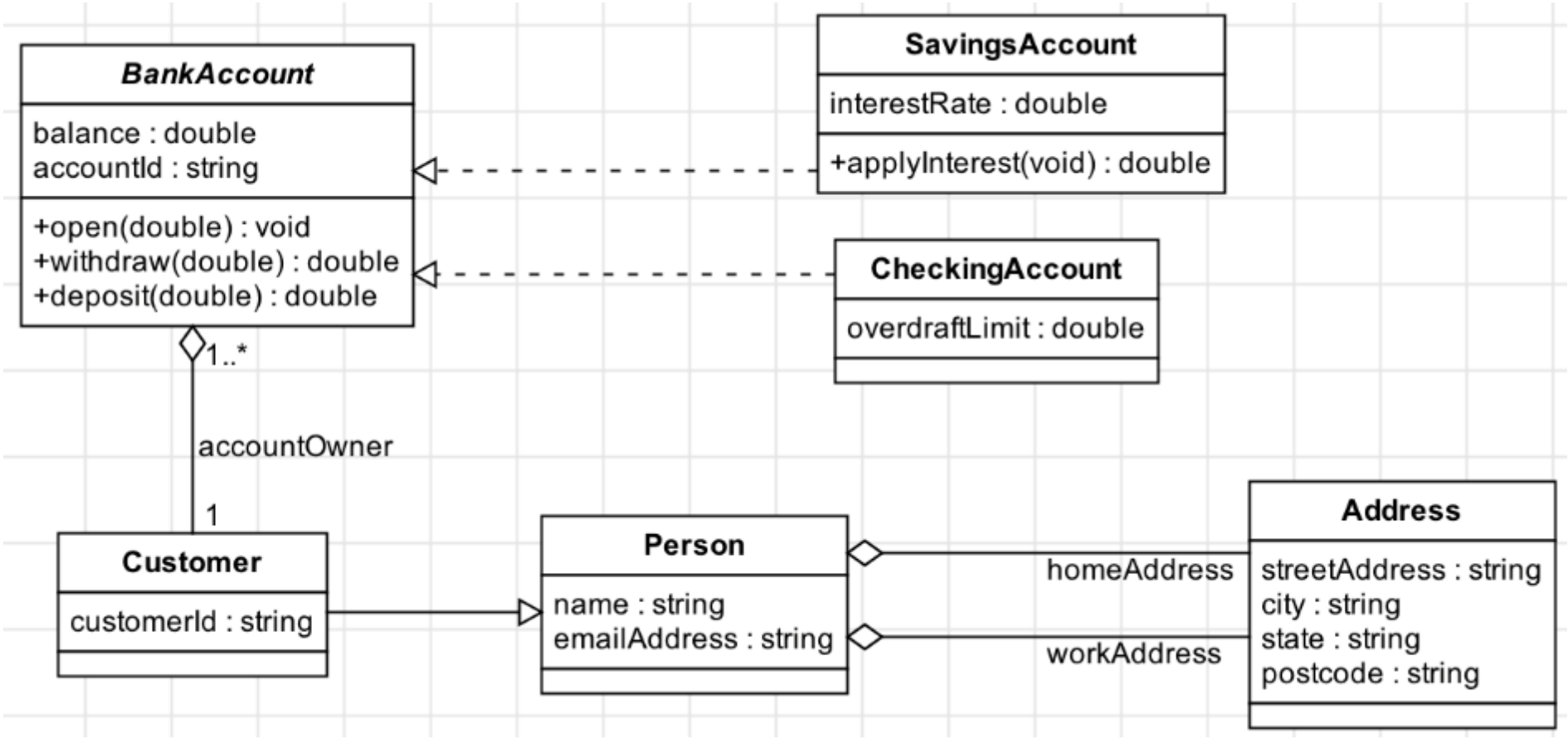

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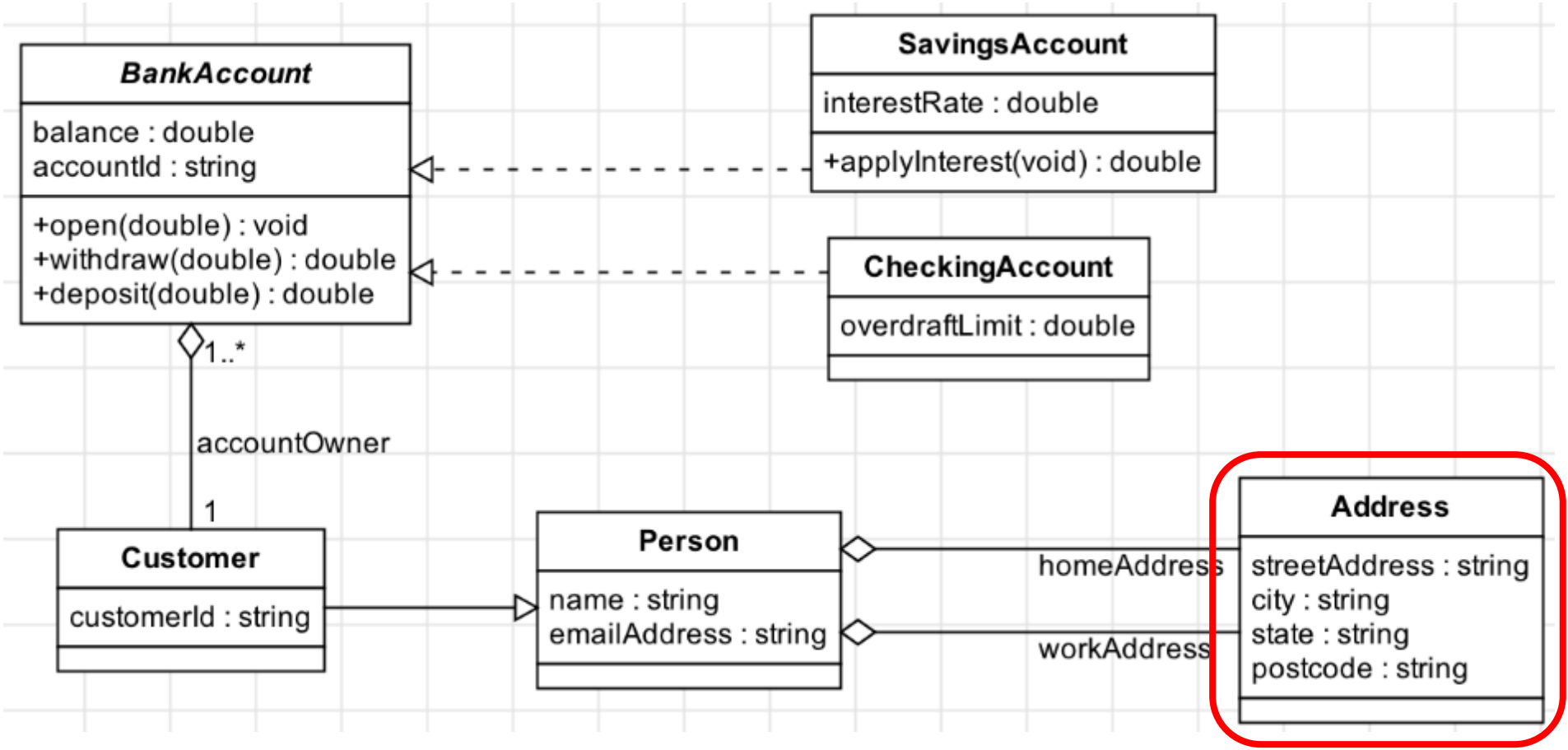
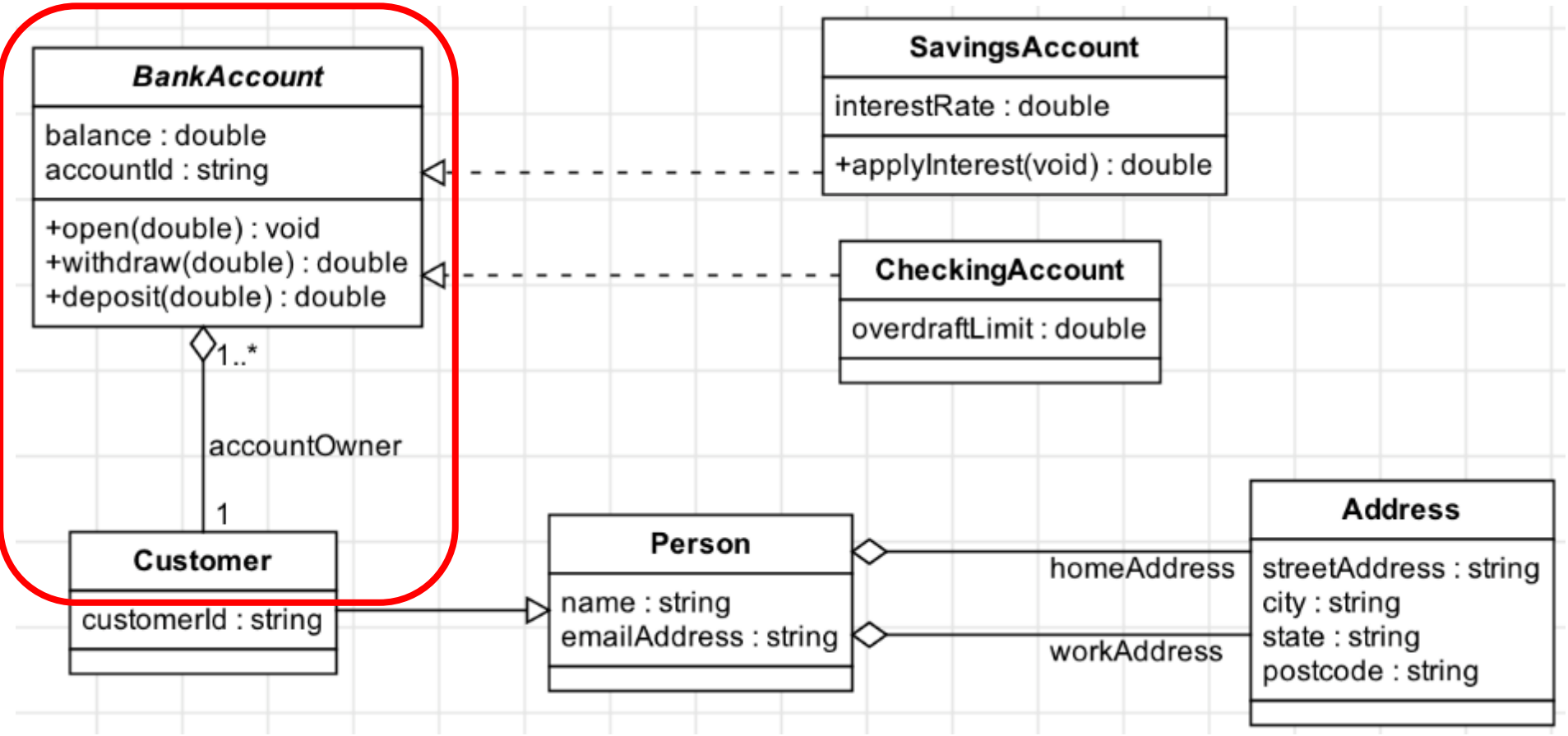
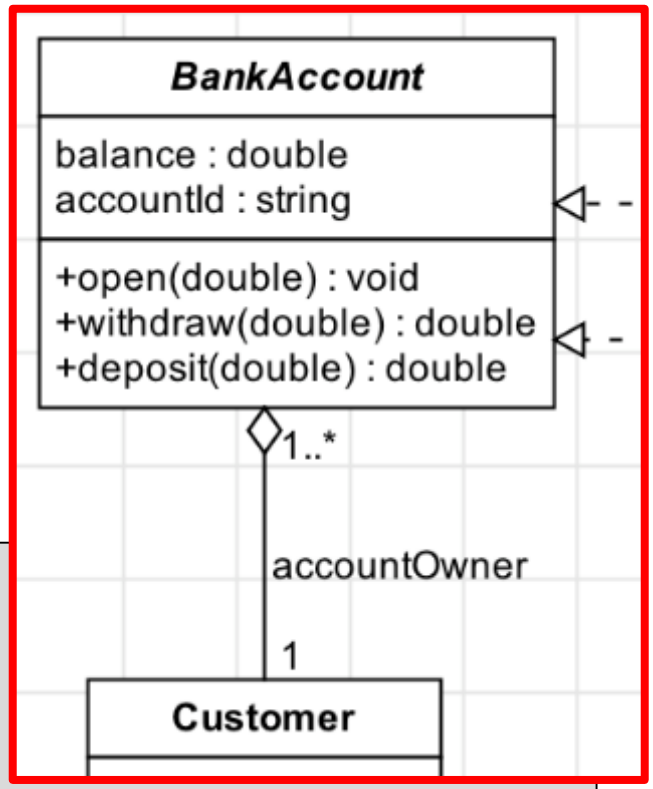


How do we convert a UML class design into Java?

UML Class Diagram (Detailed)






```
public abstract class BankAccount {

    protected double balance;
    protected String accountId;
    protected Customer accountOwner;

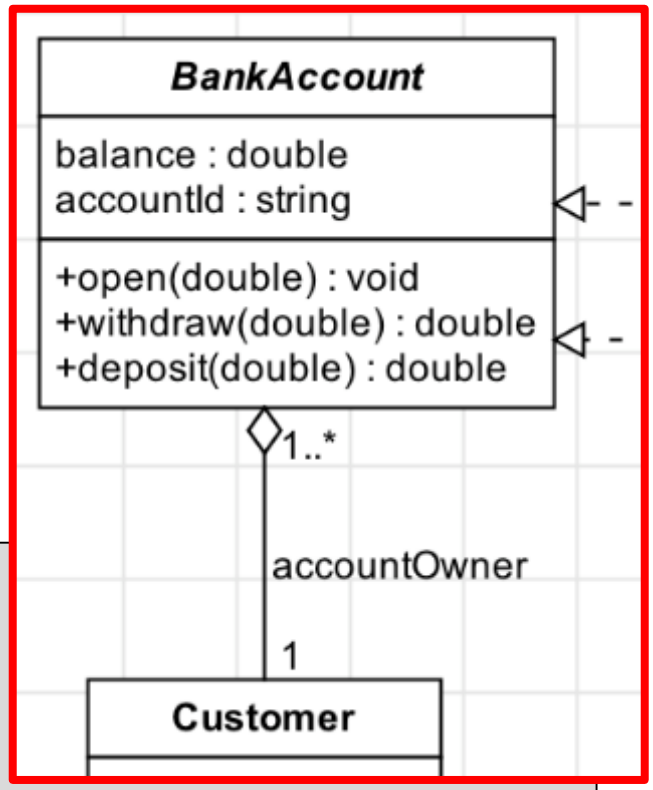
    // NOT SHOWN: constructors, get/set methods

    public void open(double initialBalance) { . . . }

    public double deposit(double amount) { . . . }

    public double withdraw(double amount) { . . . }

}
```

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public abstract class BankAccount {

    protected double balance;
    protected String accountId;
    protected Customer accountOwner;

    // NOT SHOWN: constructors, get/set methods

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    public double deposit(double amount) { . . . }

    public double withdraw(double amount) { . . . }

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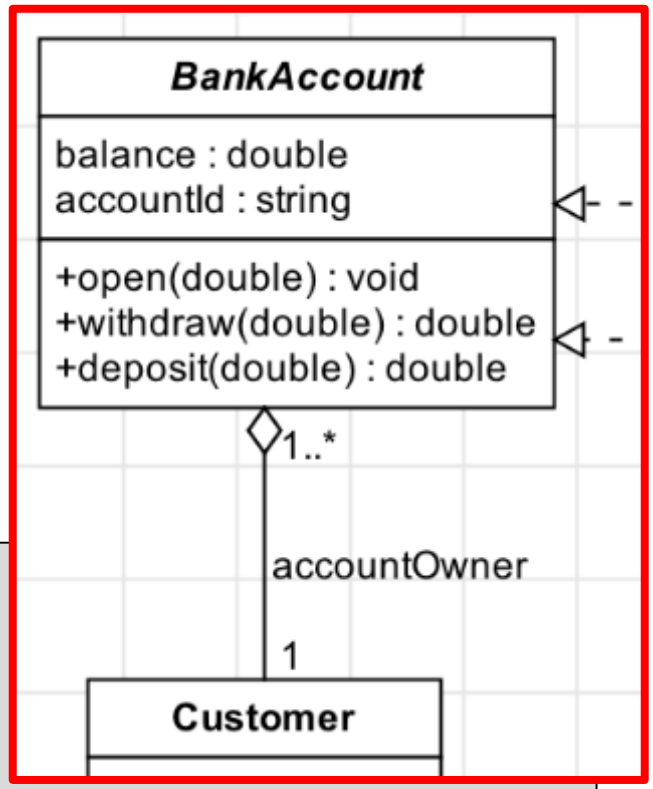


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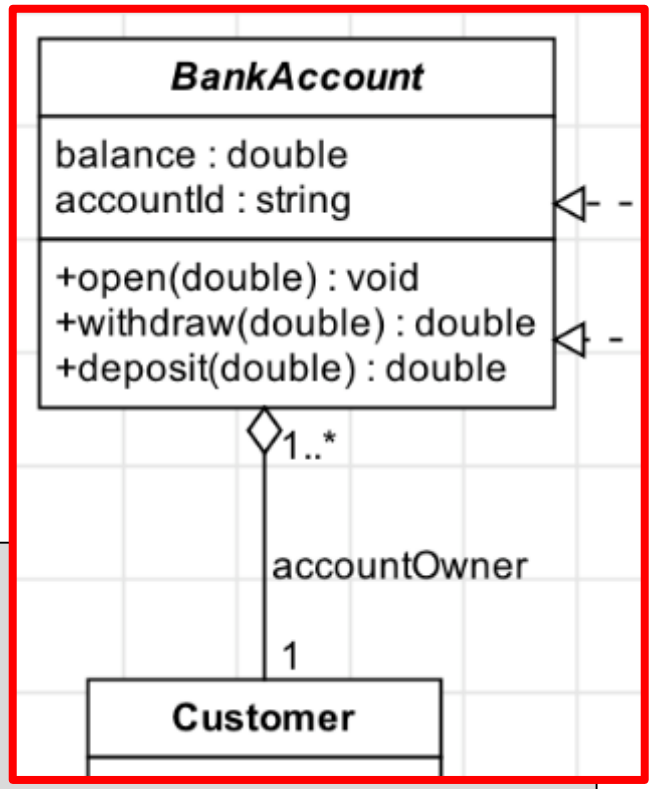


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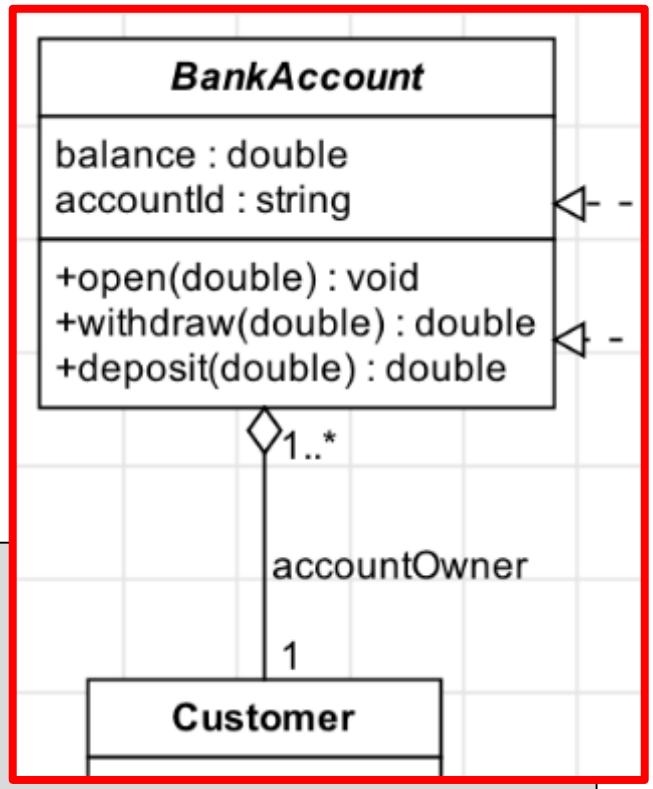


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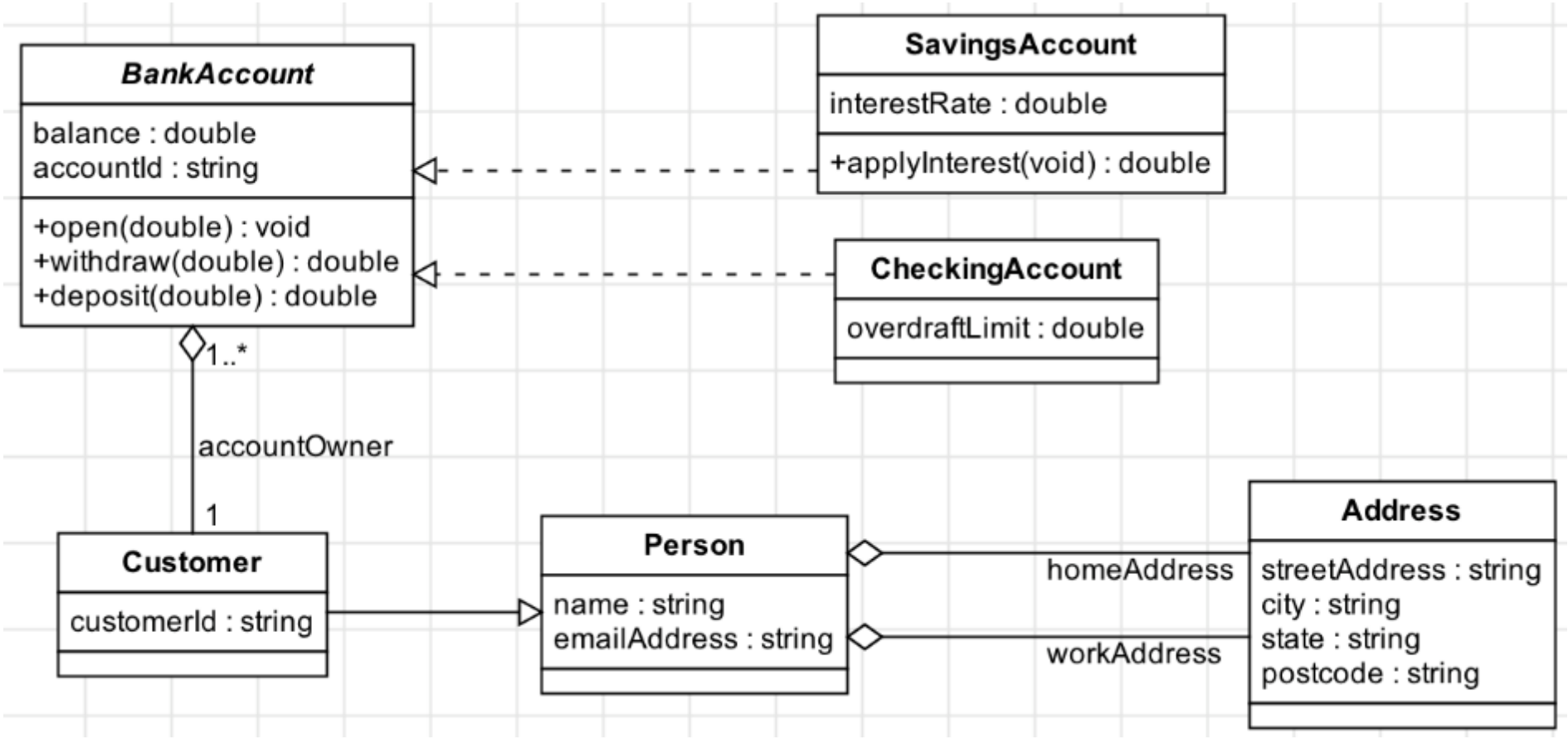
UML Class Diagram (Detailed)



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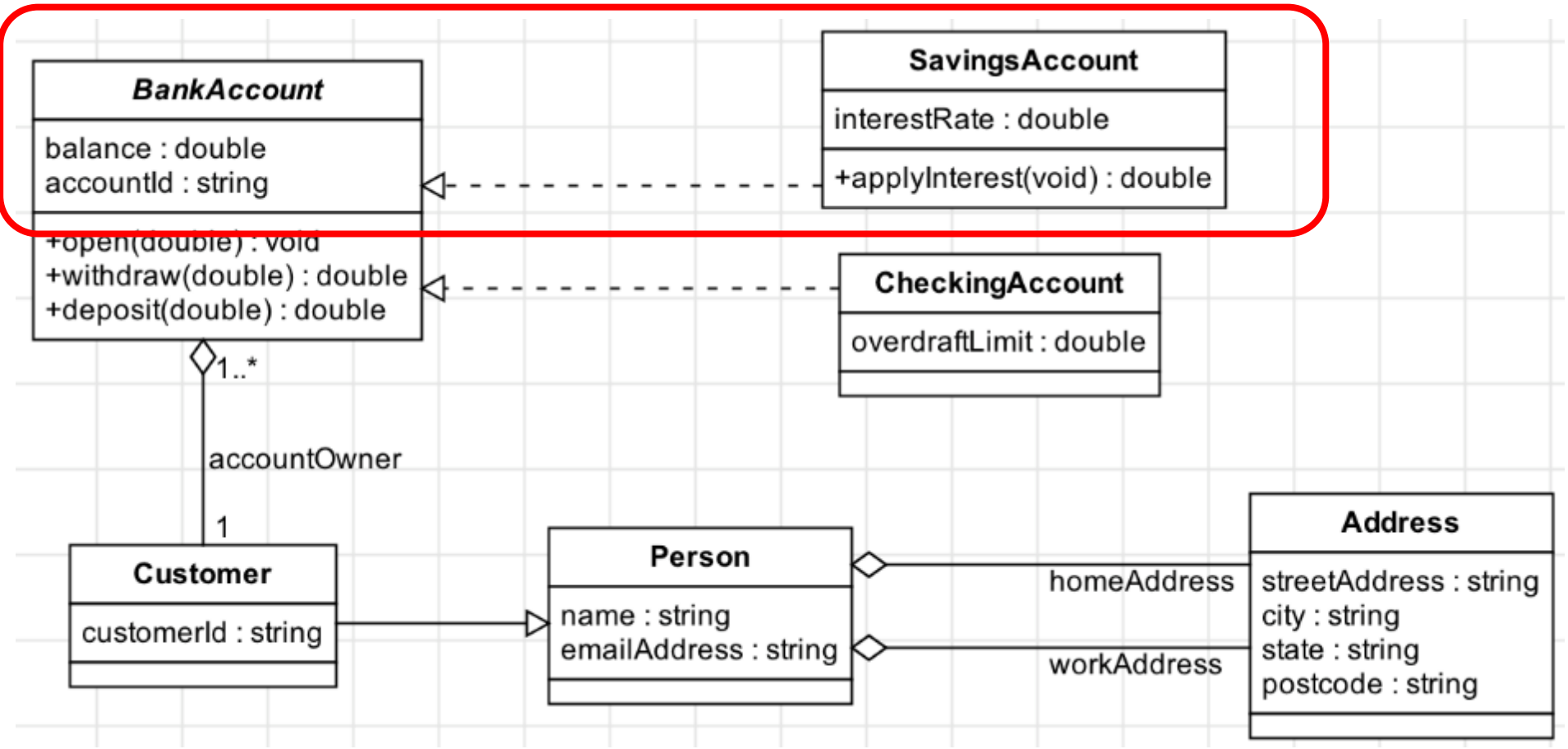

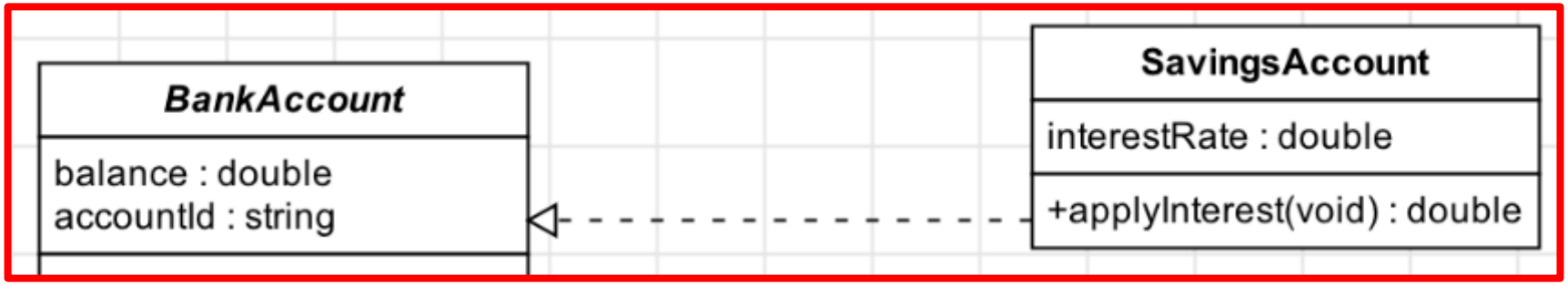


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public class SavingsAccount extends BankAccount {
    protected double interestRate;
    // NOT SHOWN: constructors, get/set methods
    public double applyInterest( ) { . . . }
}
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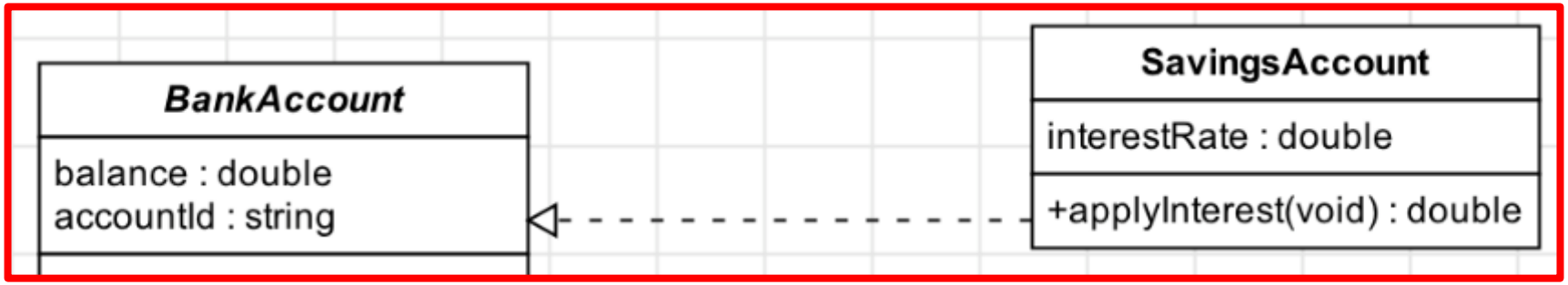


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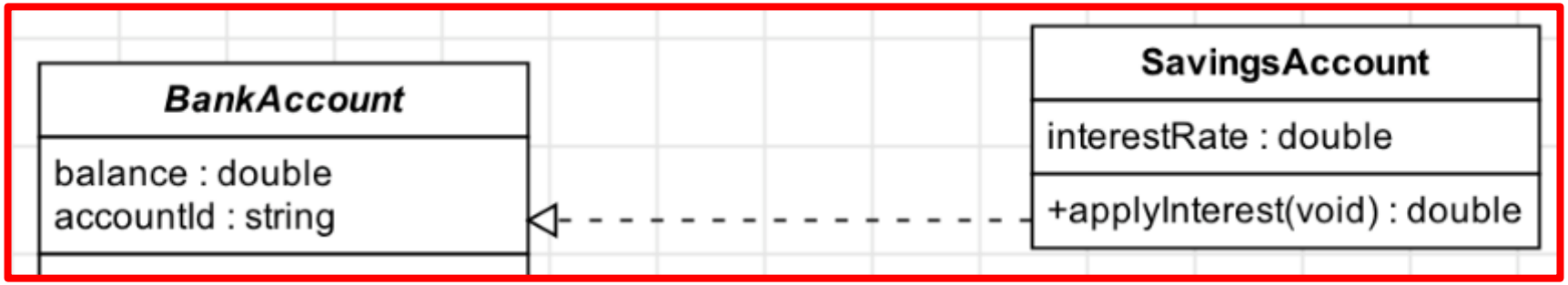


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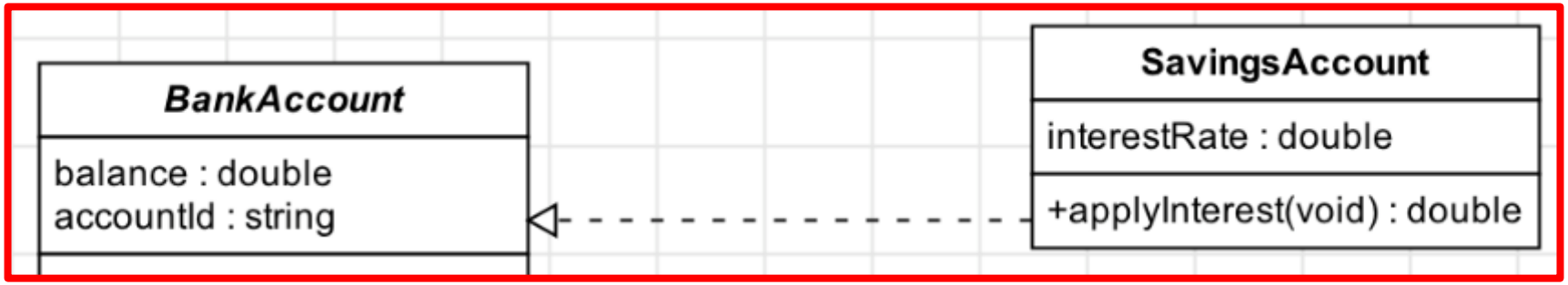


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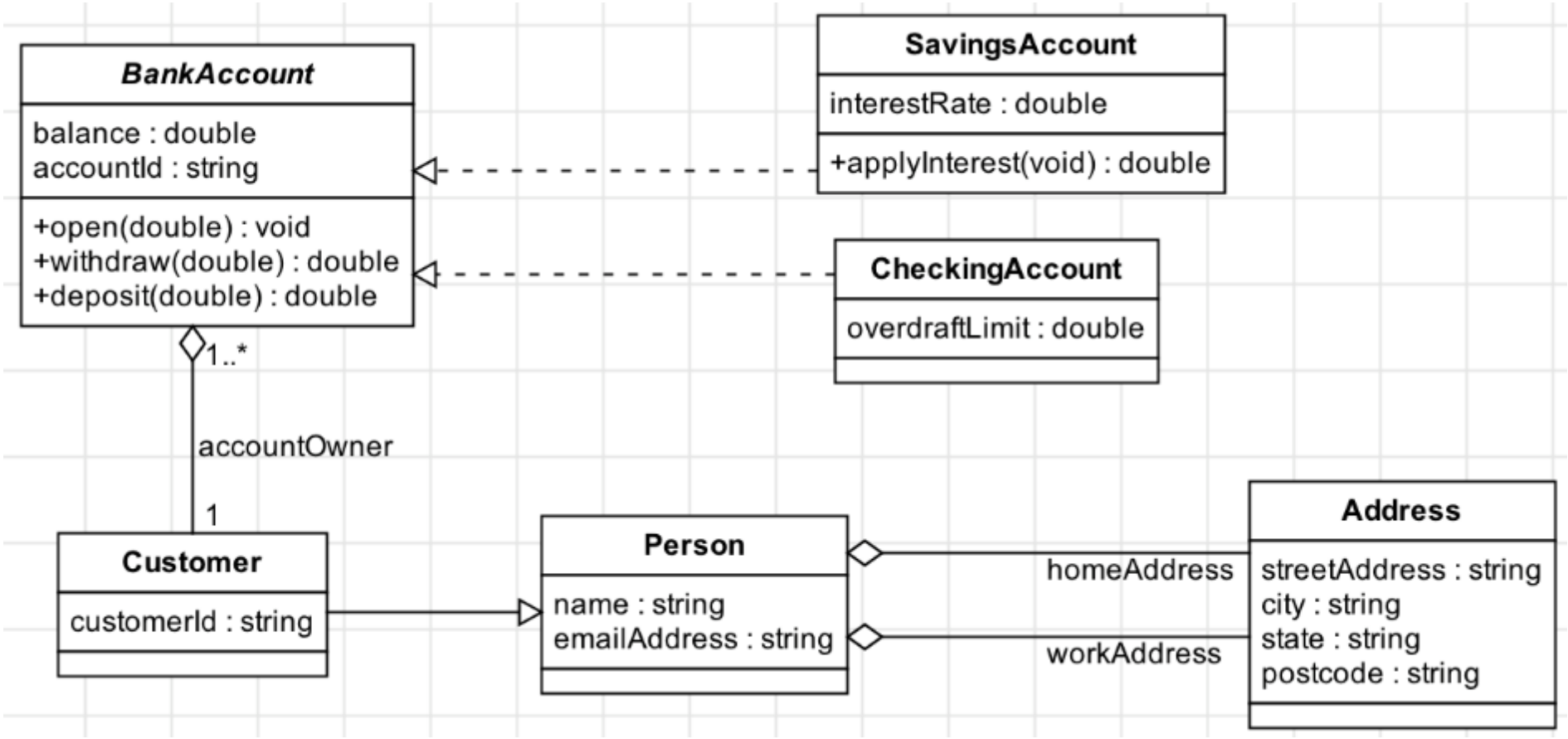

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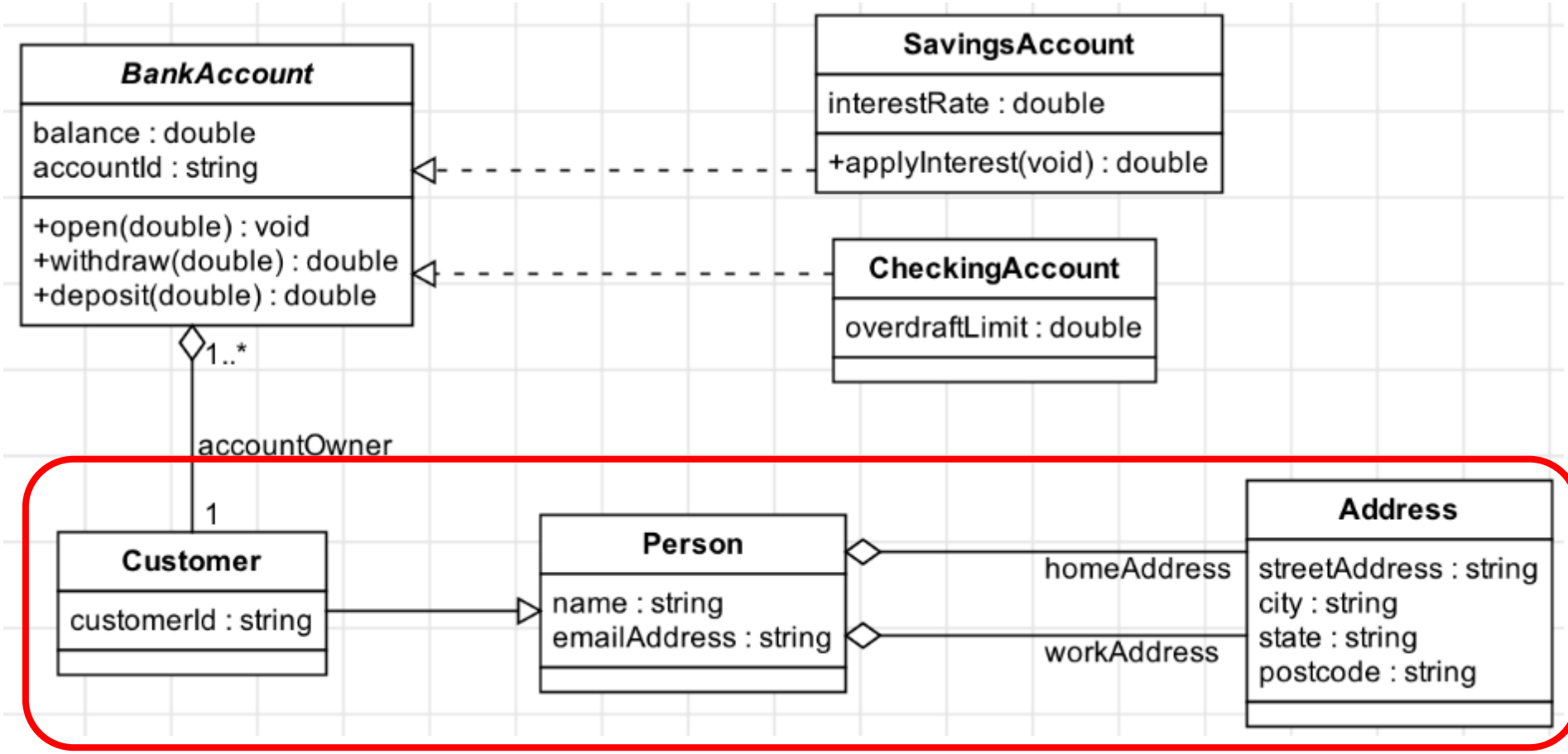

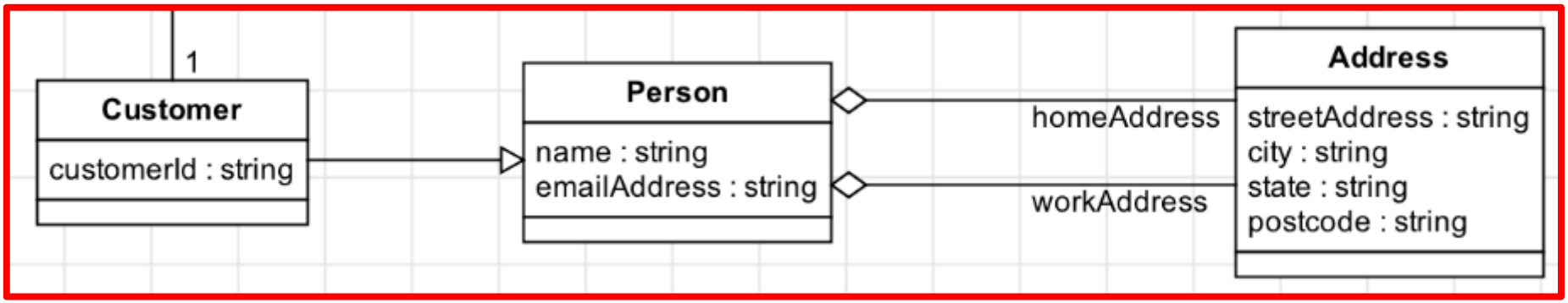


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public class Person {

    protected String name;
    protected String emailAddress;
    protected Address homeAddress;
    protected Address workAddress;

    // NOT SHOWN: constructors, get/set methods

}
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```
public class Customer extends Person {

    protected String customerId;

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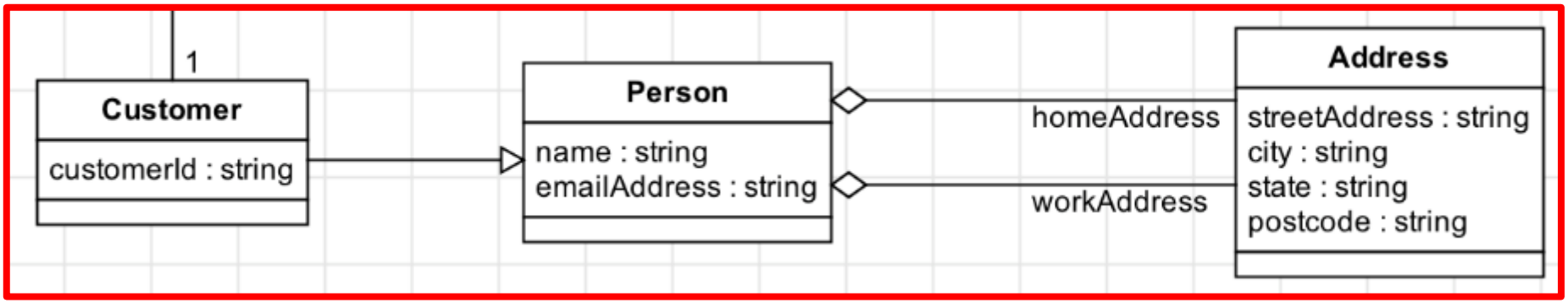


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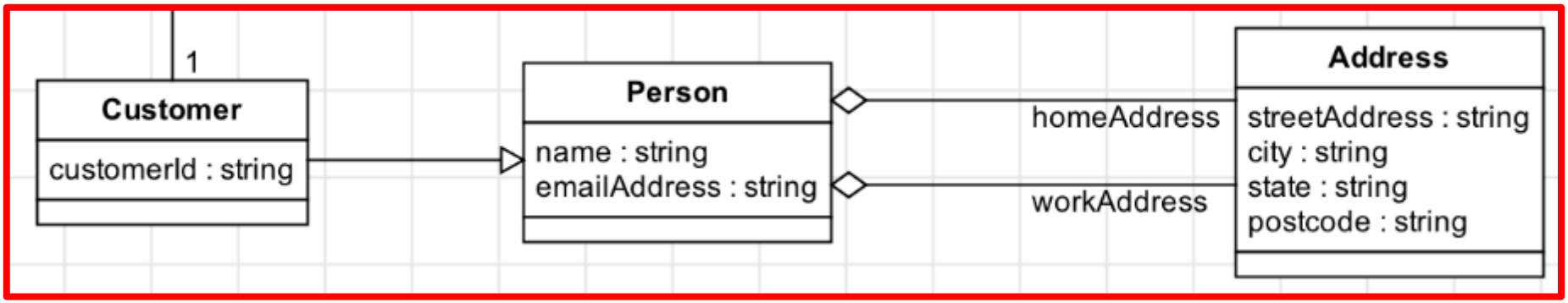


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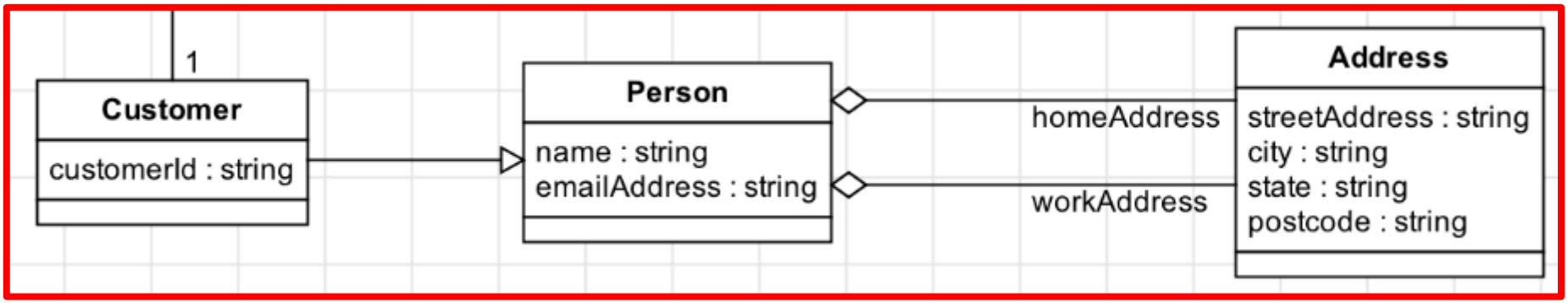


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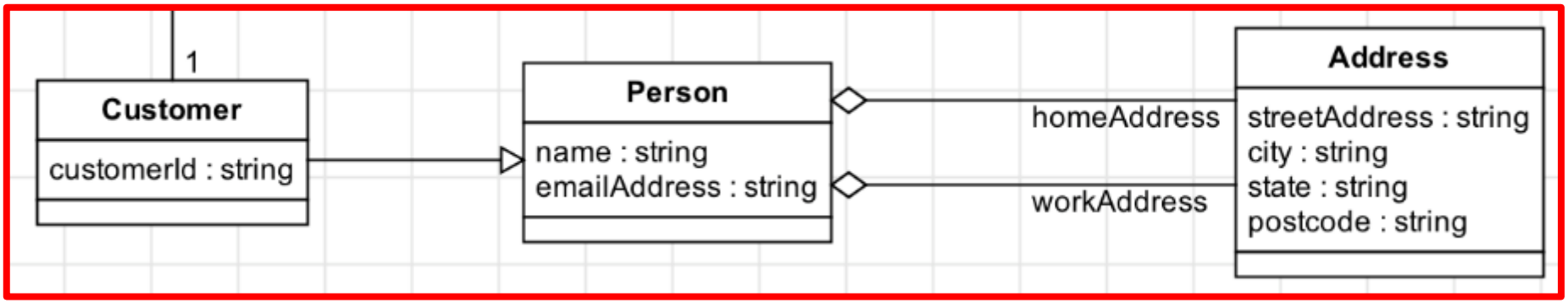


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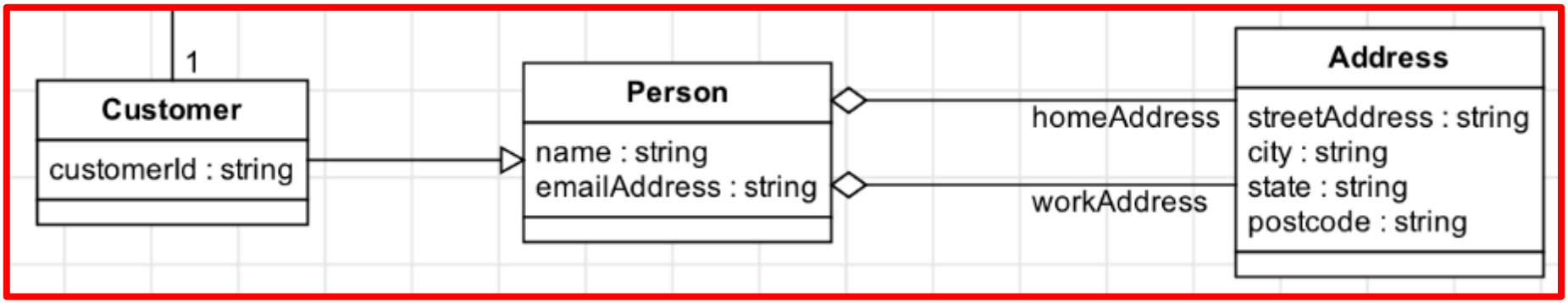


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```

Recap: Detailed UML Class Diagrams

- Allow us to show details of classes in our design
  - Fields (attributes)
  - Methods (operations)
  - Named relationships
  - Multiplicity
- Can easily be converted to Java

SD2x3.5

Software Quality

Chris


Is software getting better?

Perspectives on Quality

- **Transcendental:** can be recognized but not defined or measured
- **User:** satisfies end-users' needs
- **Manufacturer:** conforms to specification (regardless of what users want)
- **Product:** based on internal characteristics
- **Value-based:** depends on what someone is willing to pay for it

Quality Models

- **McCall:** hierarchy of factors, criteria, and metrics (1977)
- **ISO 9126:** characteristics and sub-characteristics (1991)
- **ISO 25010:** revision (2011)
- **CMU Software Engineering Institute:** performance, dependability, safety (1995)

A definition of Software Quality

- **External**: executable program running on hardware in some environment

- **Internal**: code as human-readable text

External Quality

- **Functionality:** satisfies stated or implied needs
- **Reliability:** maintains a level of performance in a given environment for a given period of time
- **Usability:** ease with which user can understand, learn, and operate the software
- **Efficiency:** limits the amount/number of resources used
- **Portability:** ease with which software can be transferred from one environment to another
- **Security:** level of confidentiality and integrity provided by the software

Internal Quality: “Maintainability”

- Ease with which a programmer can:
  - understand the code
  - add new functionality
  - modify existing functionality
  - reuse code
  - incorporate new code
  - identify and fix defects
  - **modify the code to improve external quality**

Internal Quality

Analyzability

Changeability

Stability

Testability

Analyzability

- Ease with which a programmer can **read**, **understand**, and **reason about** the code

- Identify and fix defects
- Add or improve functionality
- Understand how an algorithm (solution) is implemented
- Improve other aspects of software quality (efficiency, security, etc.)

Changeability

- Ease with which a programmer can **change** the code

- Fix defects
- Add or improve functionality
- Incorporate new code
- Improve other aspects of software quality (efficiency, security, etc.)

Stability

- Extent to which the code is **tolerant** of changes to other parts of the code
- Changes in one part of code don't require changes in other parts
- Reduce time/effort required to change code, since you won't also need to change other code

Testability

- Ease with which a the code can be **tested**

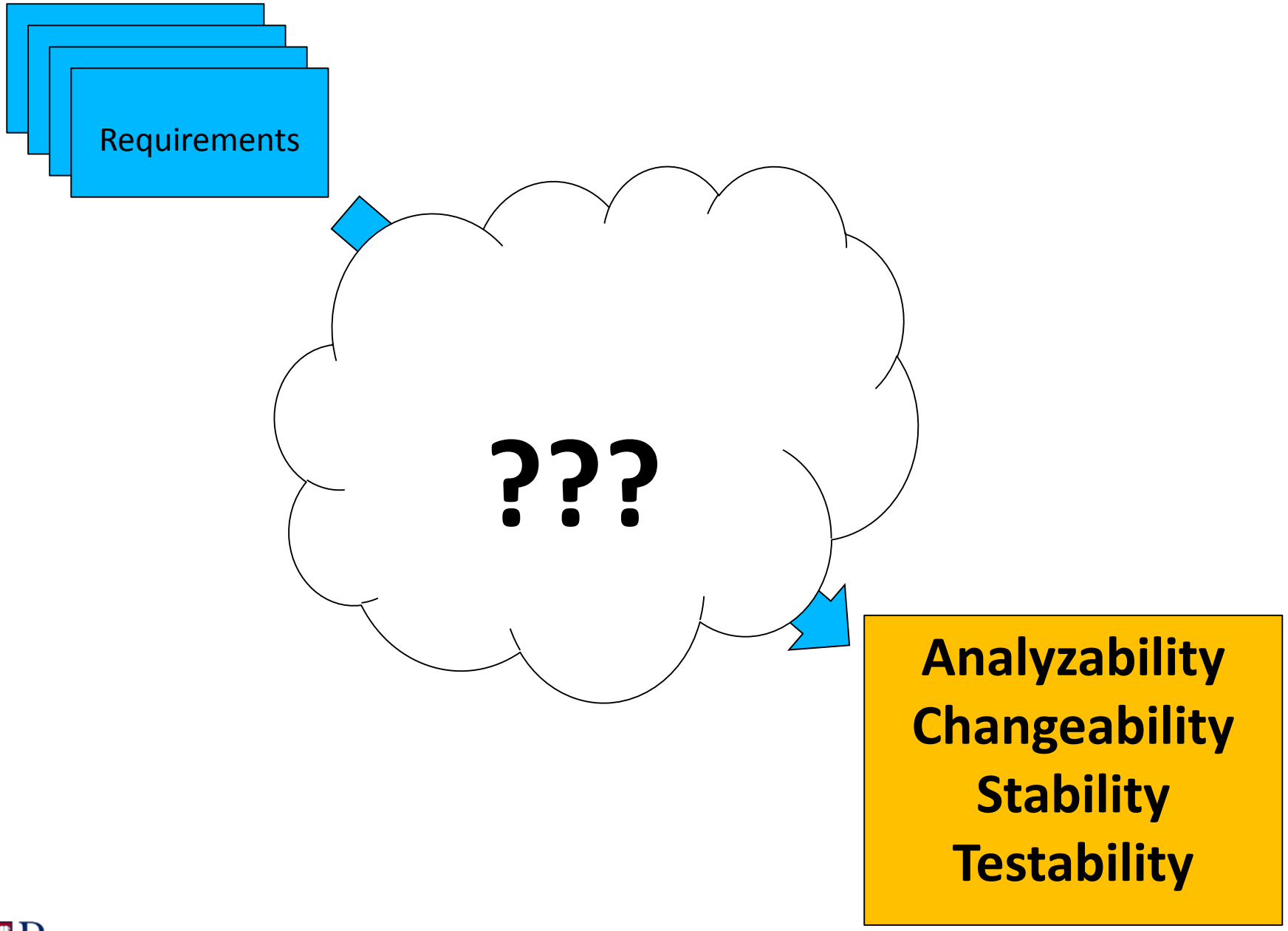
- Create test cases
- Identify and fix defects
- Increase confidence that software is working correctly


Times change,
people change,
situations change,
relationships change.
The only thing
constant is change.

SD2x3.6

Software Design Concepts

Chris


Requirements
???
Analyzability
Changeability
Stability
Testability

How do we design software?

1. Modeling: identify concepts and their relationships
2. Choose the right architecture
3. Create/Use appropriate data structures
4. Use design patterns when appropriate
5. Refactor (change the design) as necessary

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Motivating Example

- Design a Java program that reads a file containing info about courses, instructors, and enrollment

- And then allows the user to choose to see either:
  - the instructor(s) for a given course
  - the average enrollment for the course

The Monolith!

- A **single** piece of code (main method) that:
  - Reads the data from the file and puts it into a data structure
  - Prompts the user for the operation to perform (show instructors for a course, or show average enrollment for a course)
  - Prompts the user to enter the course number
  - Performs the operation and handles errors accordingly
  - Shows the results to the user

What's wrong with the Monolith?

What's wrong with the Monolith?

- **analyzability:** main method can be fairly long
- **changeability:** hard to find the code you want to change
- **stability:** hard to know whether a change in one place will affect other places
- **testability:** if something goes wrong, hard to find the bug
- hard to **reuse** any of the code

How can we address these problems?

High-level design (Architecture)

- Divide system into subsystems (components, or combinations of components) that address major features
- Each subsystem should be able to do its work with minimal dependency on other subsystems

- Examples:
  - Model-View-Controller (MVC)
  - Software as a Service (SaaS)
  - N-Tier

Three-Tier Architecture

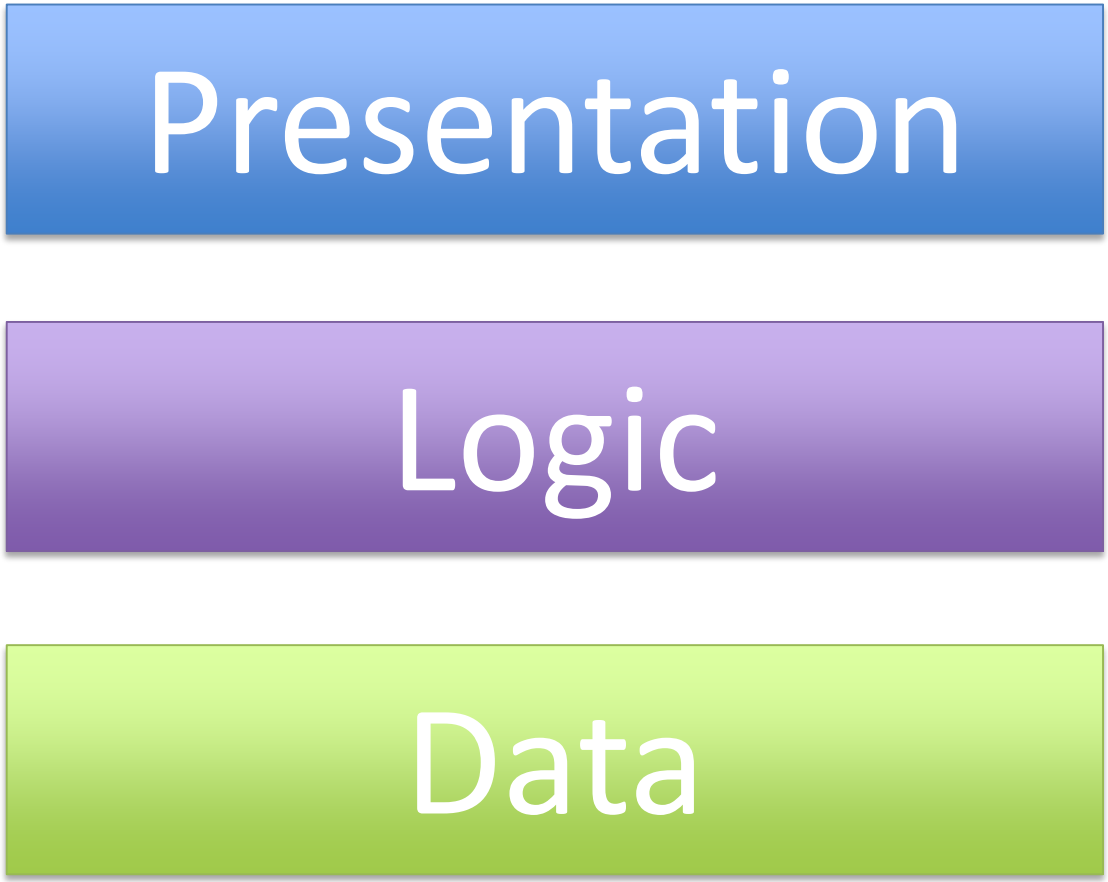
Get input from user.
Display output.

Three-Tier Architecture

Get input from user.
Display output.

Perform calculations.
Make decisions.

Three-Tier Architecture

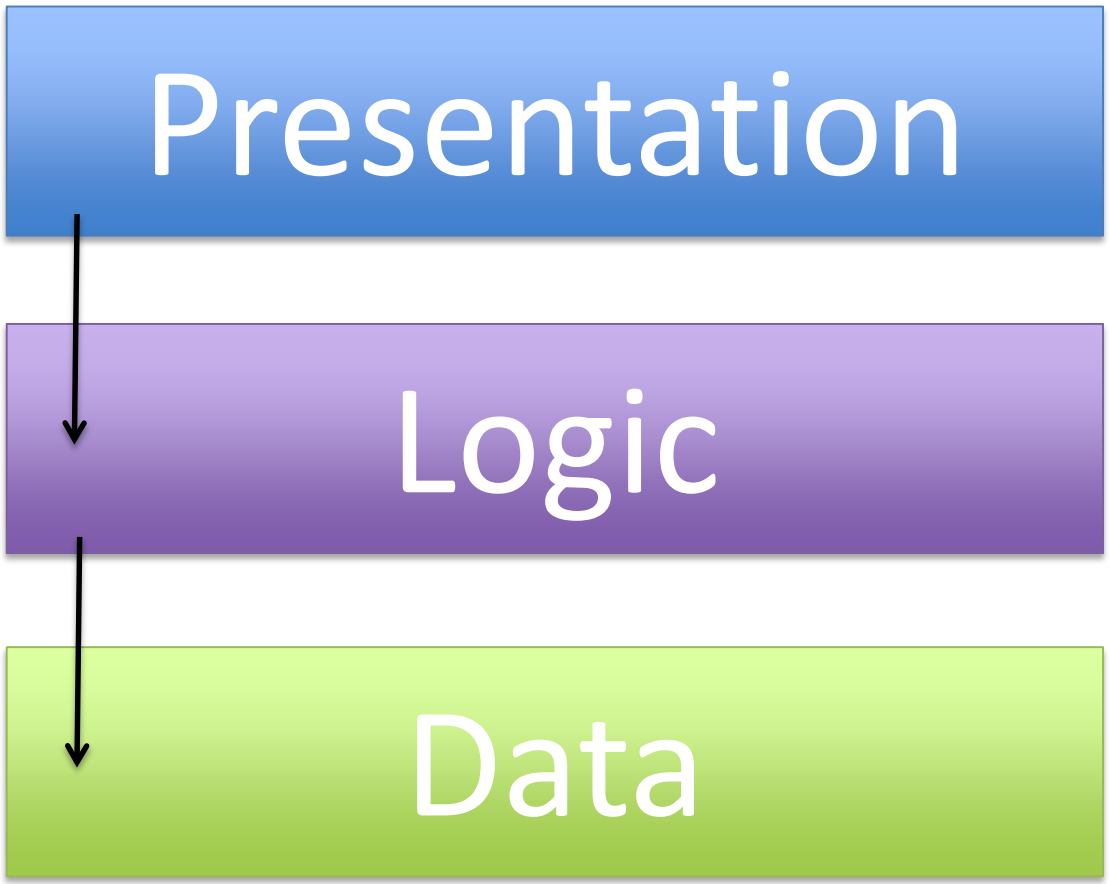


Get input from user.
Display output.

Perform calculations.
Make decisions.

Store and retrieve data.

Three-Tier Architecture



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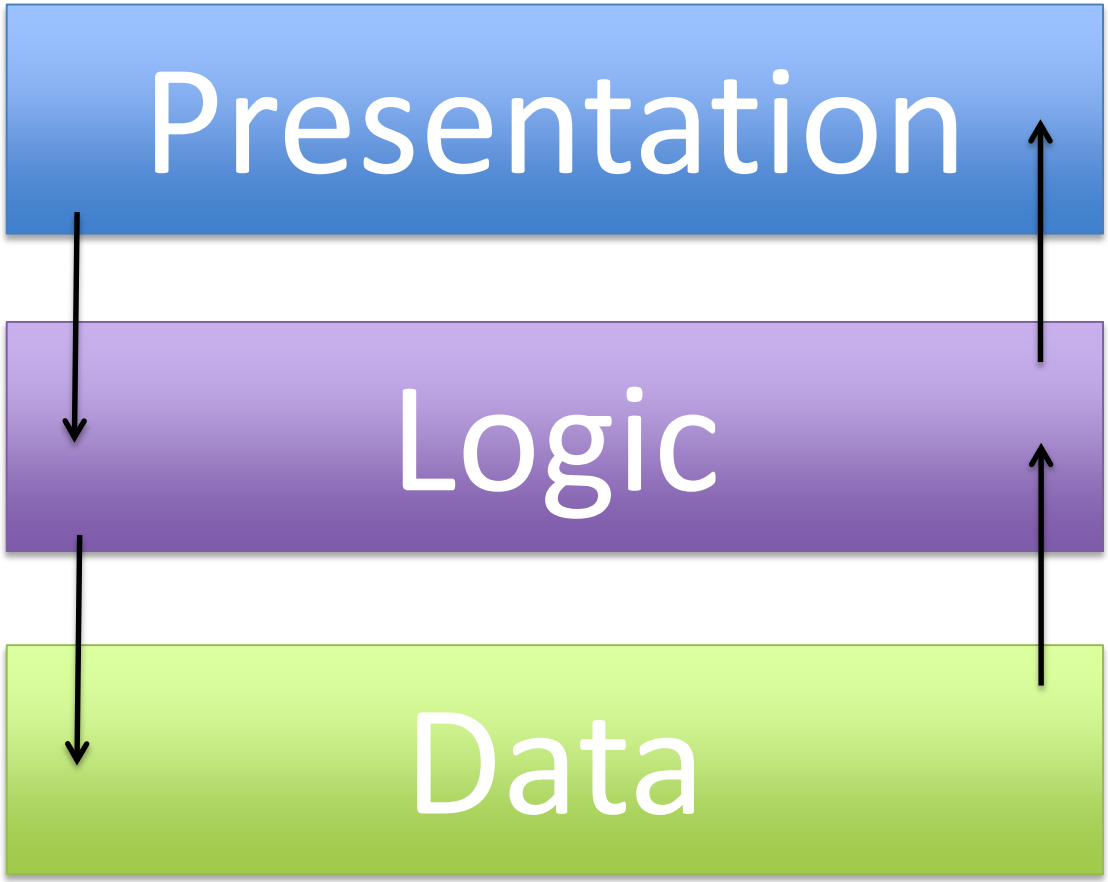

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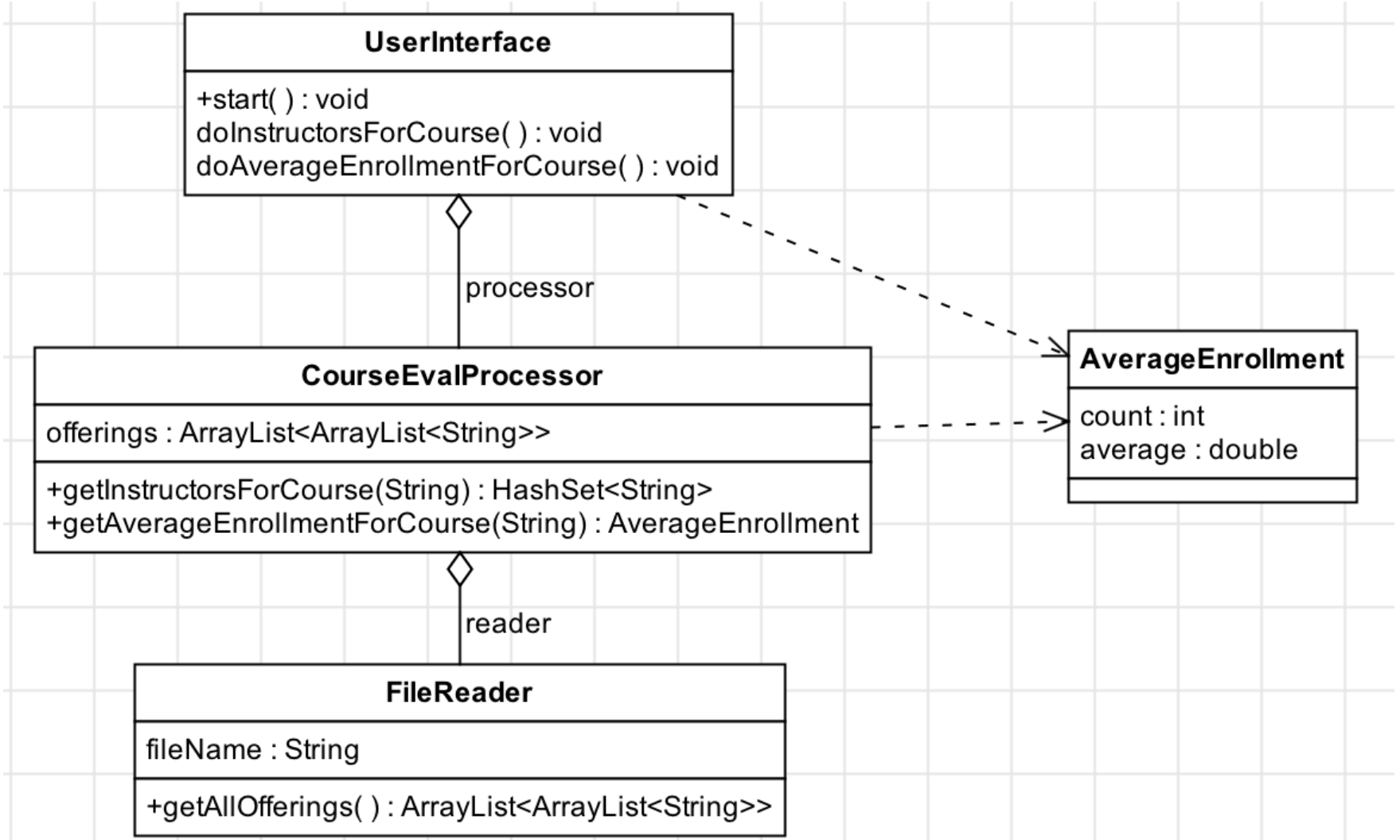
Applying the Three-Tier Architecture



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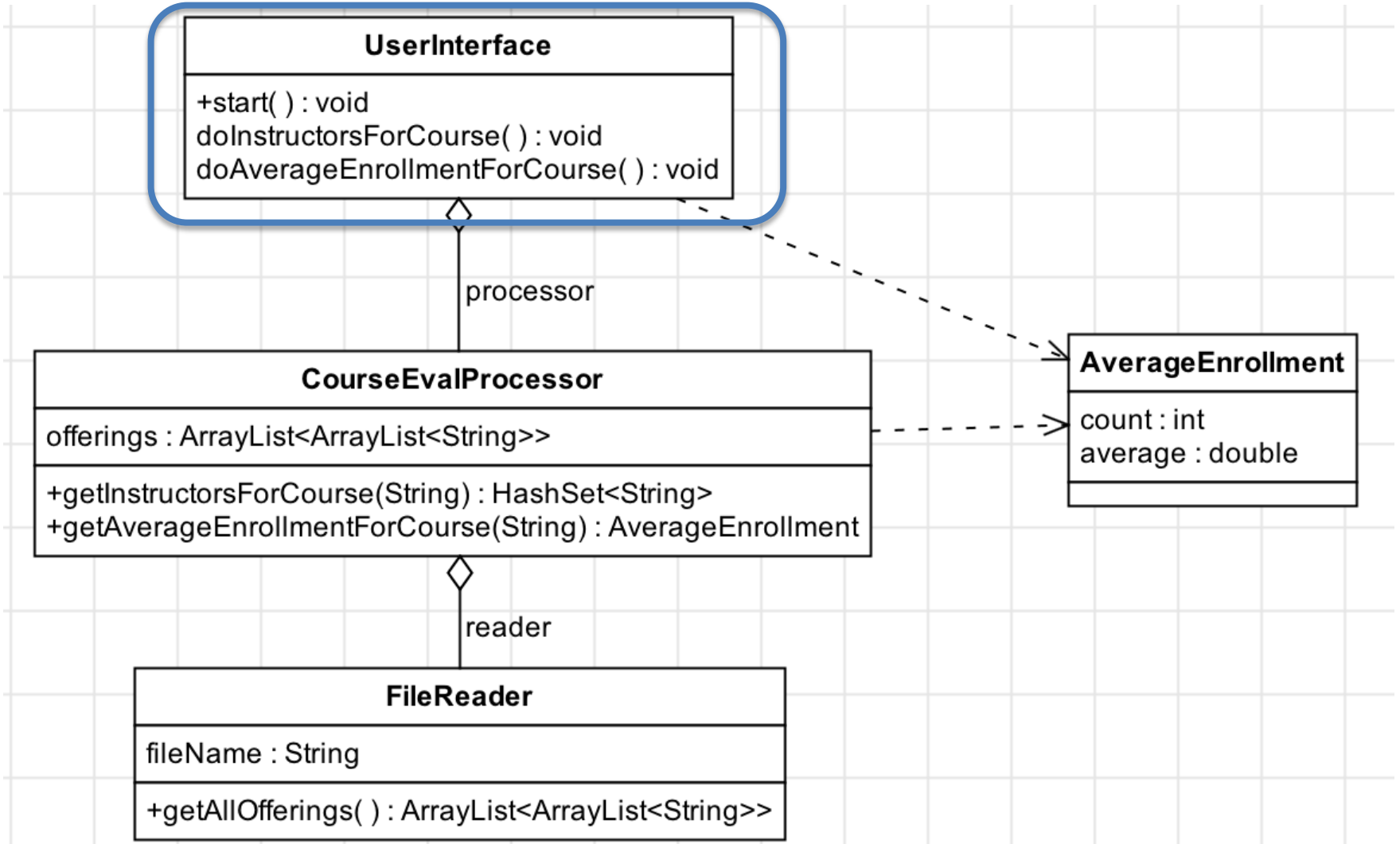

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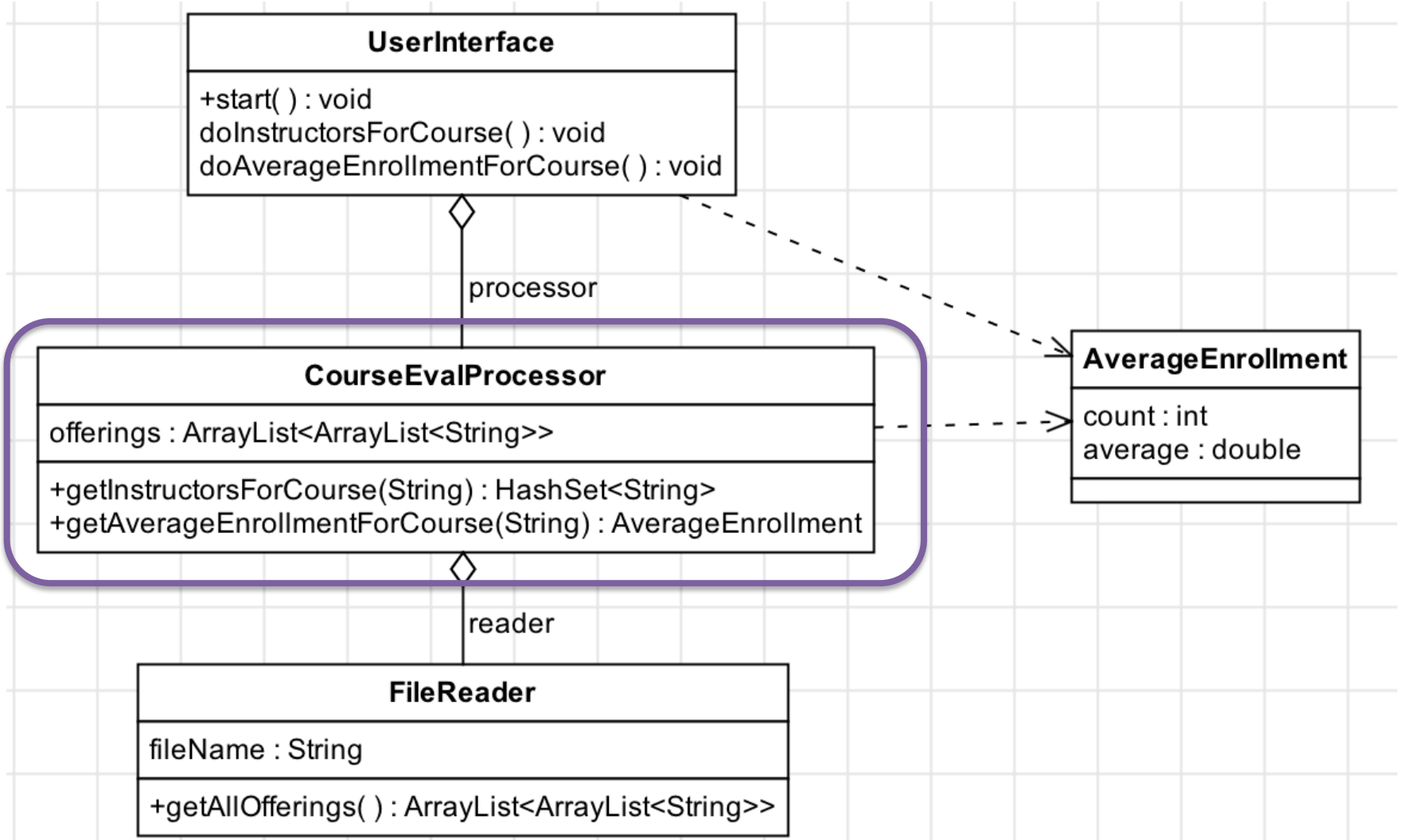

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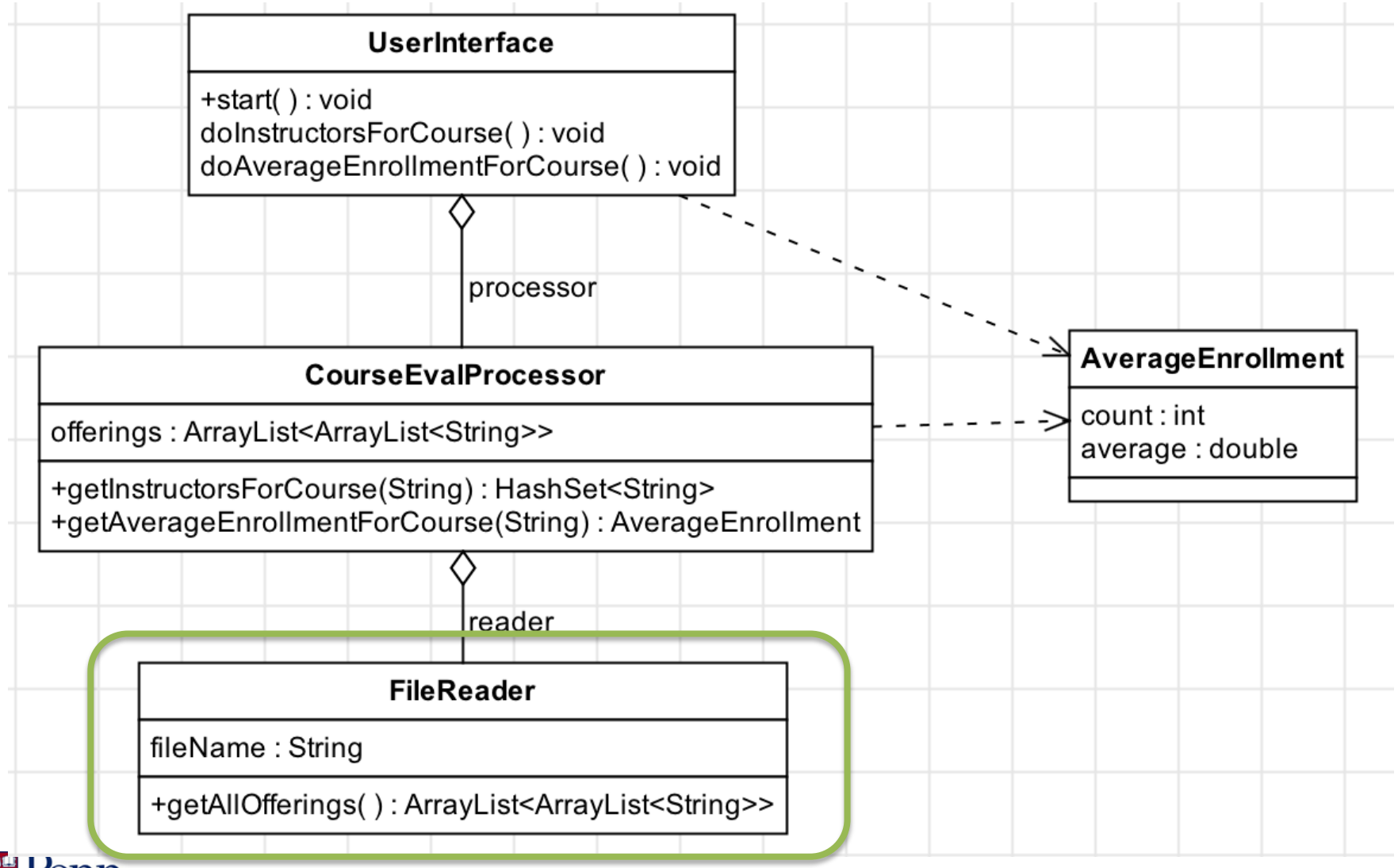

Why is this better than Monolith?

- **analyzability:** the program is divided into smaller pieces that are easier to read and understand
- **changeability:** easier to find the code you want to change; less code to change
- **stability:** can change one piece without worrying about its effect on others
- **testability:** easy to test each of these separately
- can **reuse** different parts of the code

How can we achieve internal quality?

Software Design Concepts

- **Modularity:** each component addresses a single part of the functionality
- **Functional Independence:** components should have minimal dependence on other components
- **Abstraction:** components should be able to use other components with minimal knowledge of the details of their implementation

SD2x3.7

Modularity

Chris

Internal Quality

Analyzability

Changeability

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Software Design Concepts

Modularity

Functional Independence

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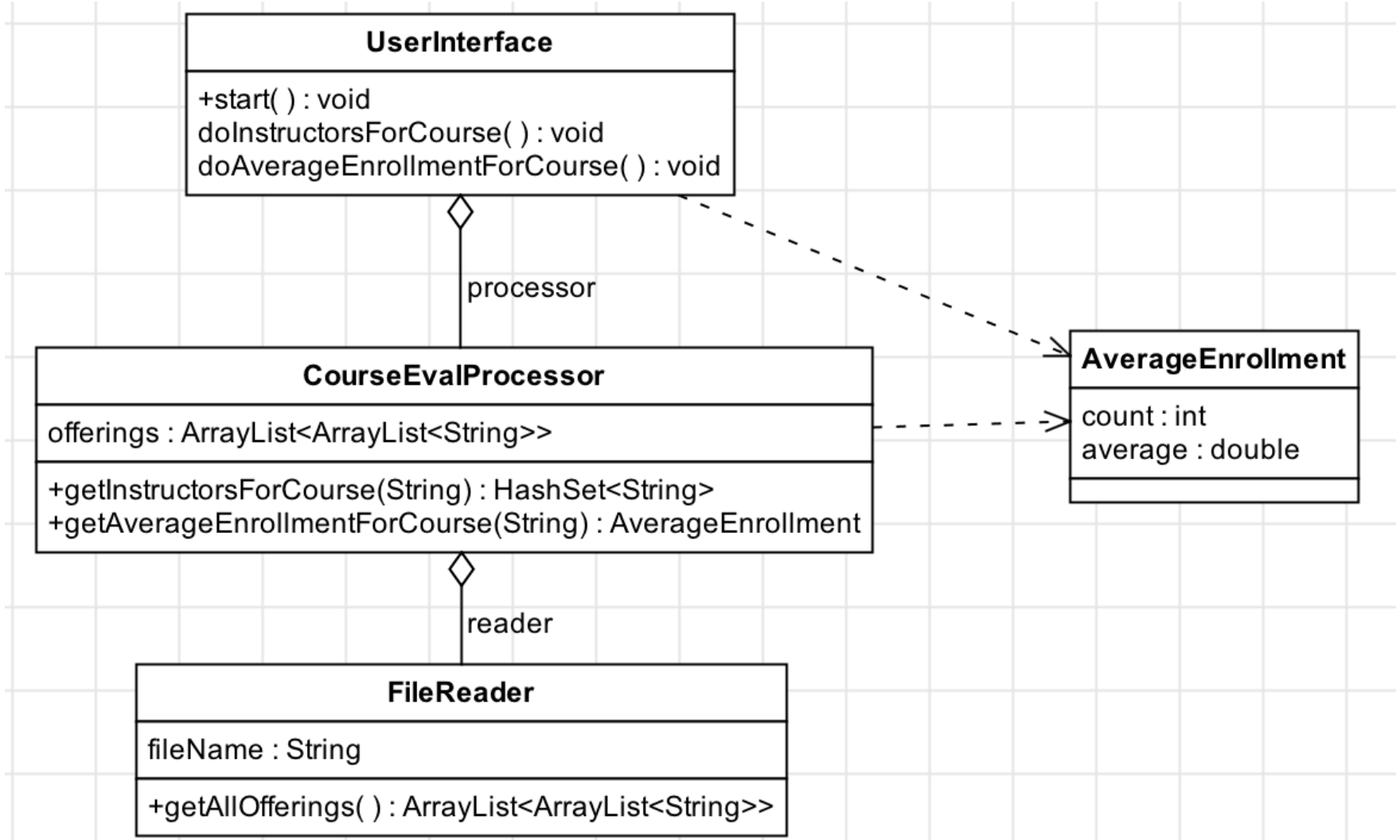
A Modular Design



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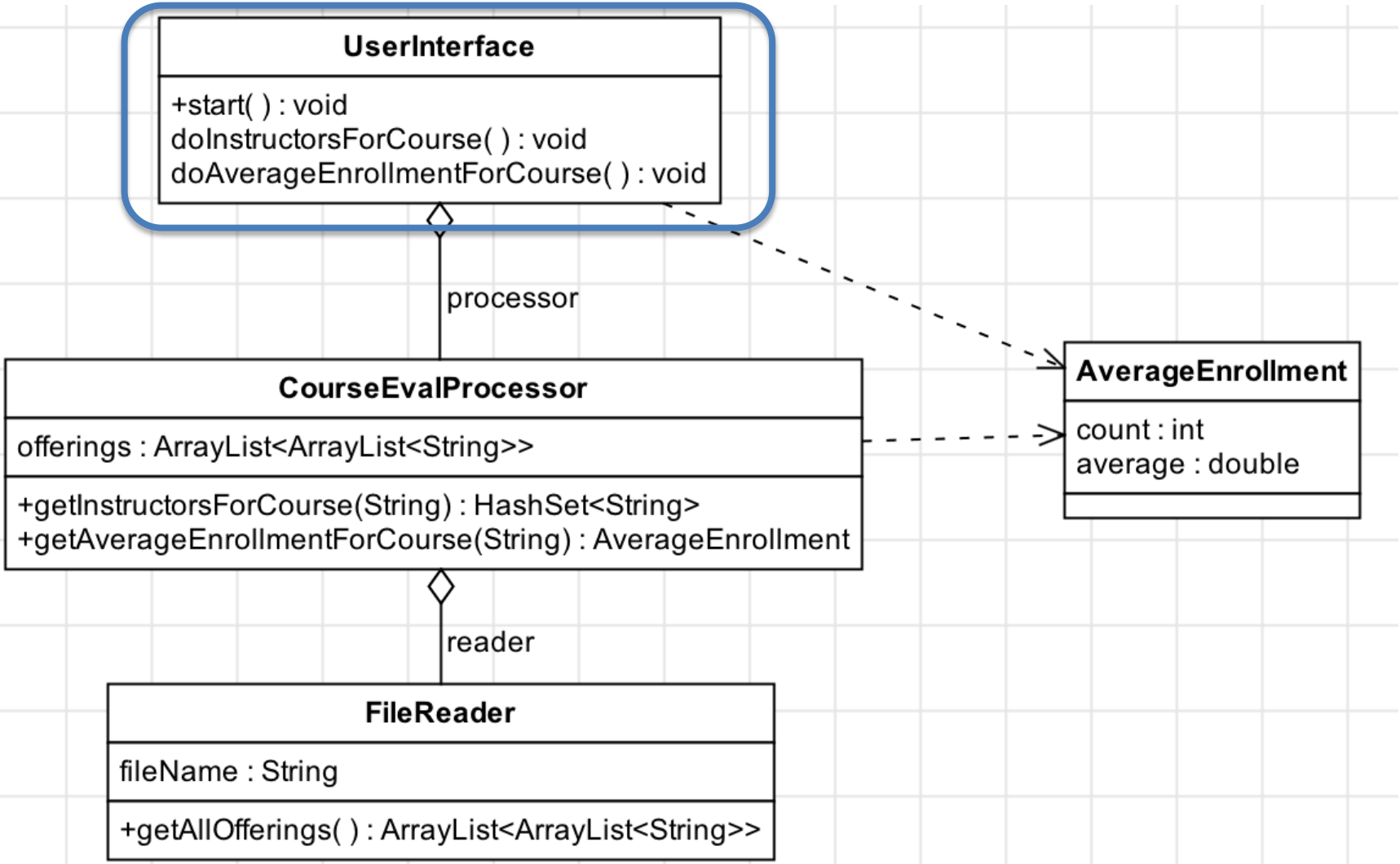

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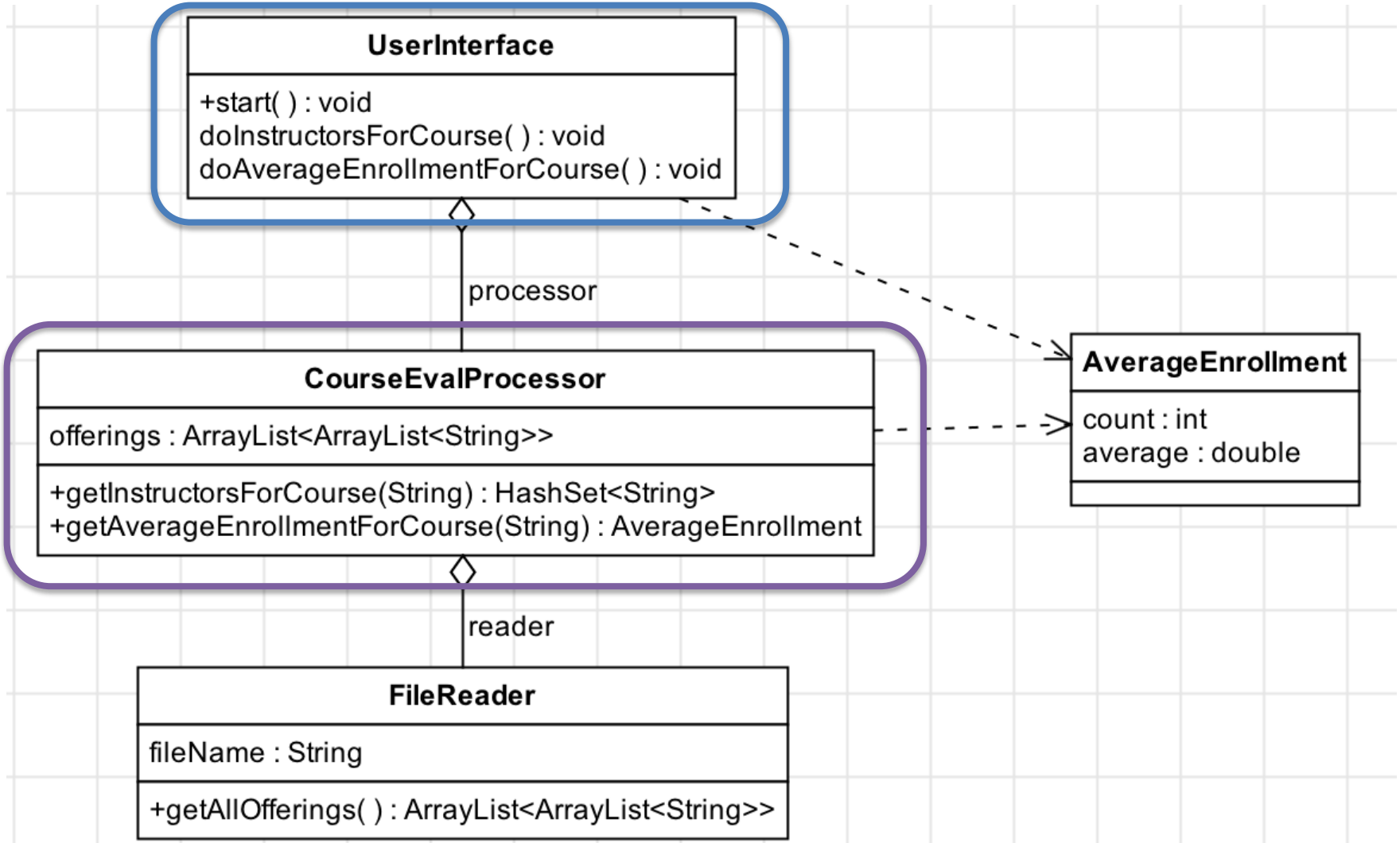

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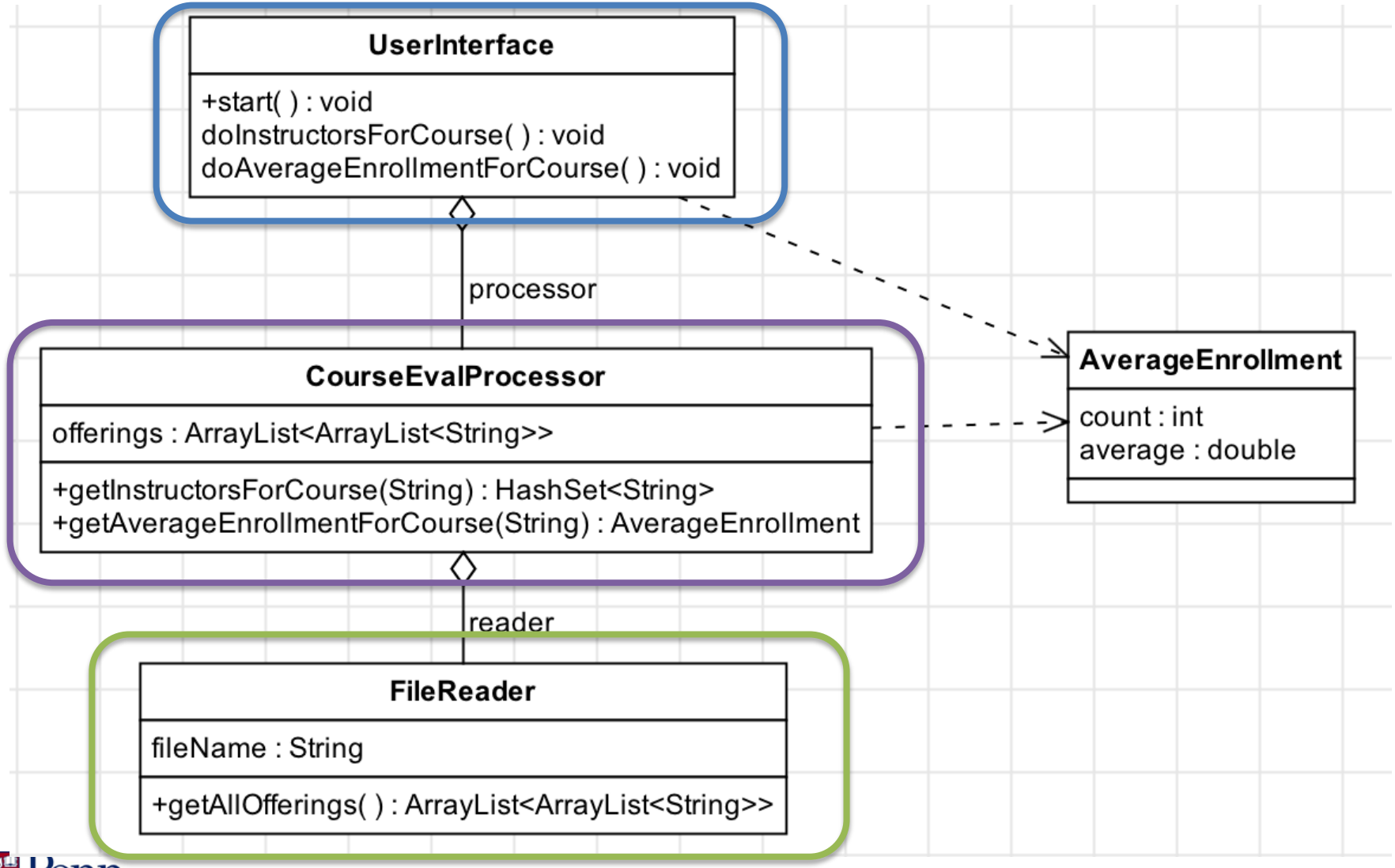


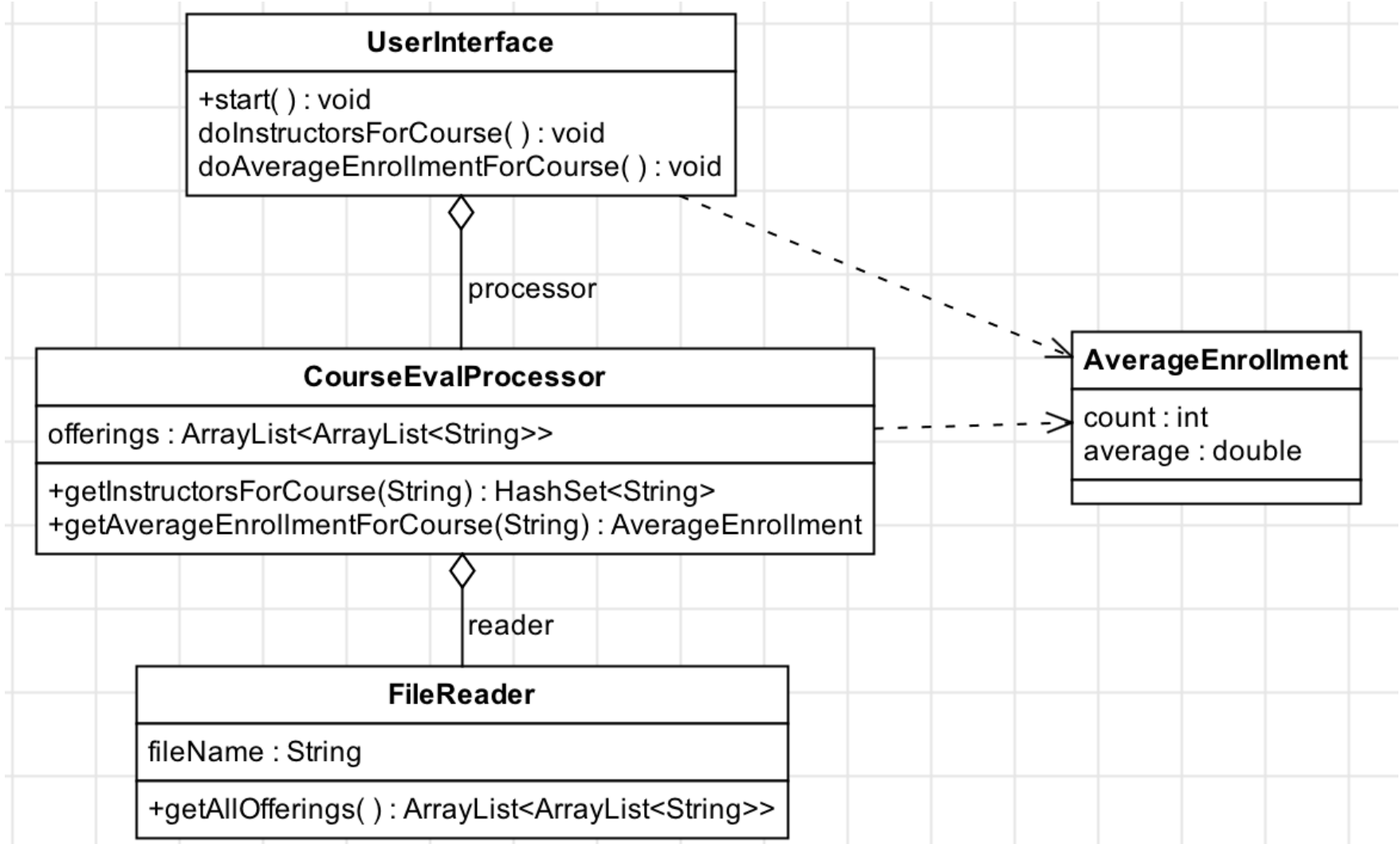
Modularity: “Separation of Concerns”

- Each component (“module”) addresses a single part of the functionality
- In Java, this is often accomplished simply by creating separate classes
- **Single Responsibility Principle:** “a class should only have one reason to change”

Why Modularity?

- **Analyzability:** leads to smaller pieces of code, each of which is easier to understand
- **Testability:** permits testing of individual pieces; easier to find and fix bugs
- **"Reusability":** pieces of code can be reused in this application or in other applications
- **Changeability:** easy to find code that needs to be changed (and then change it!)

What could change?



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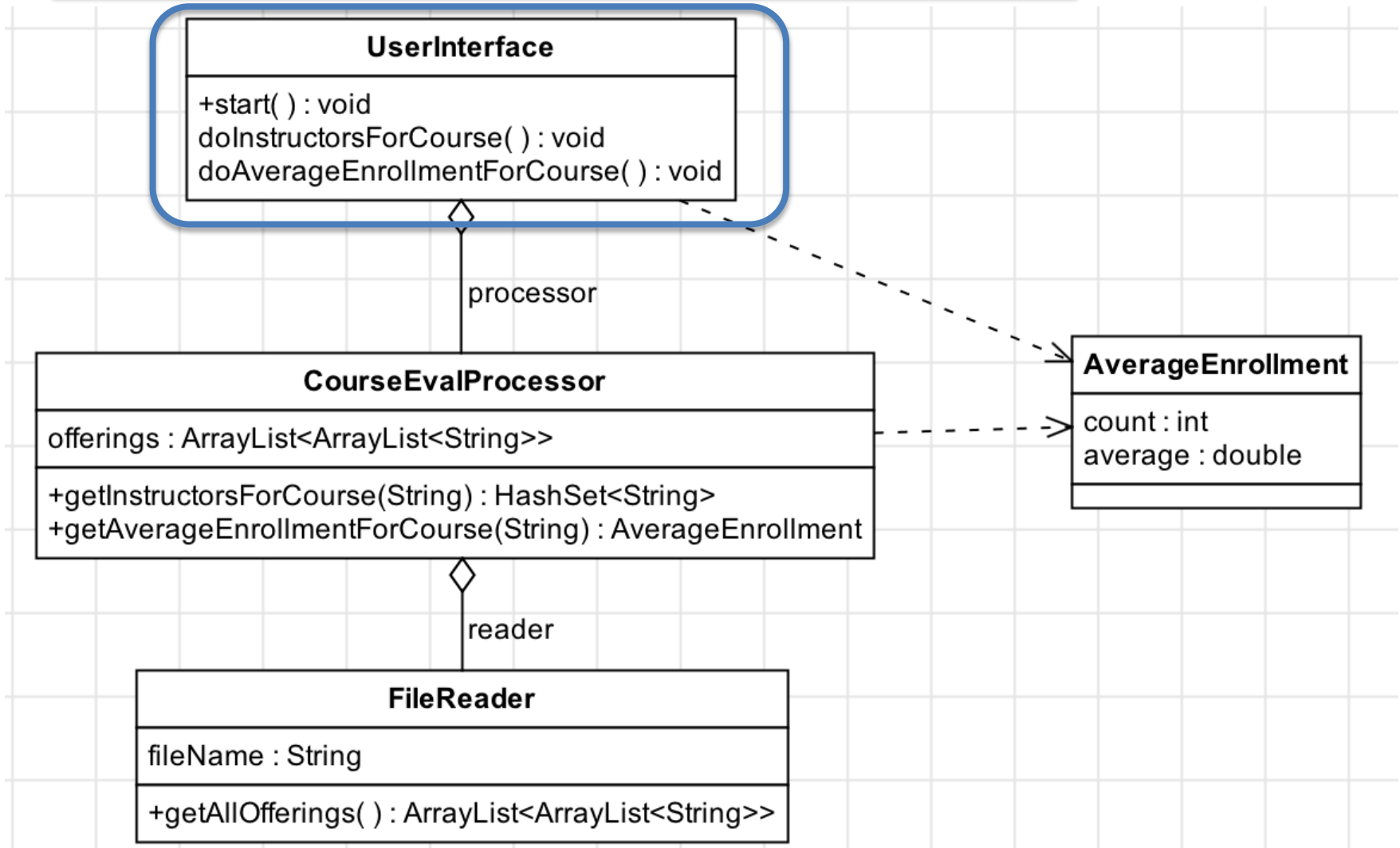
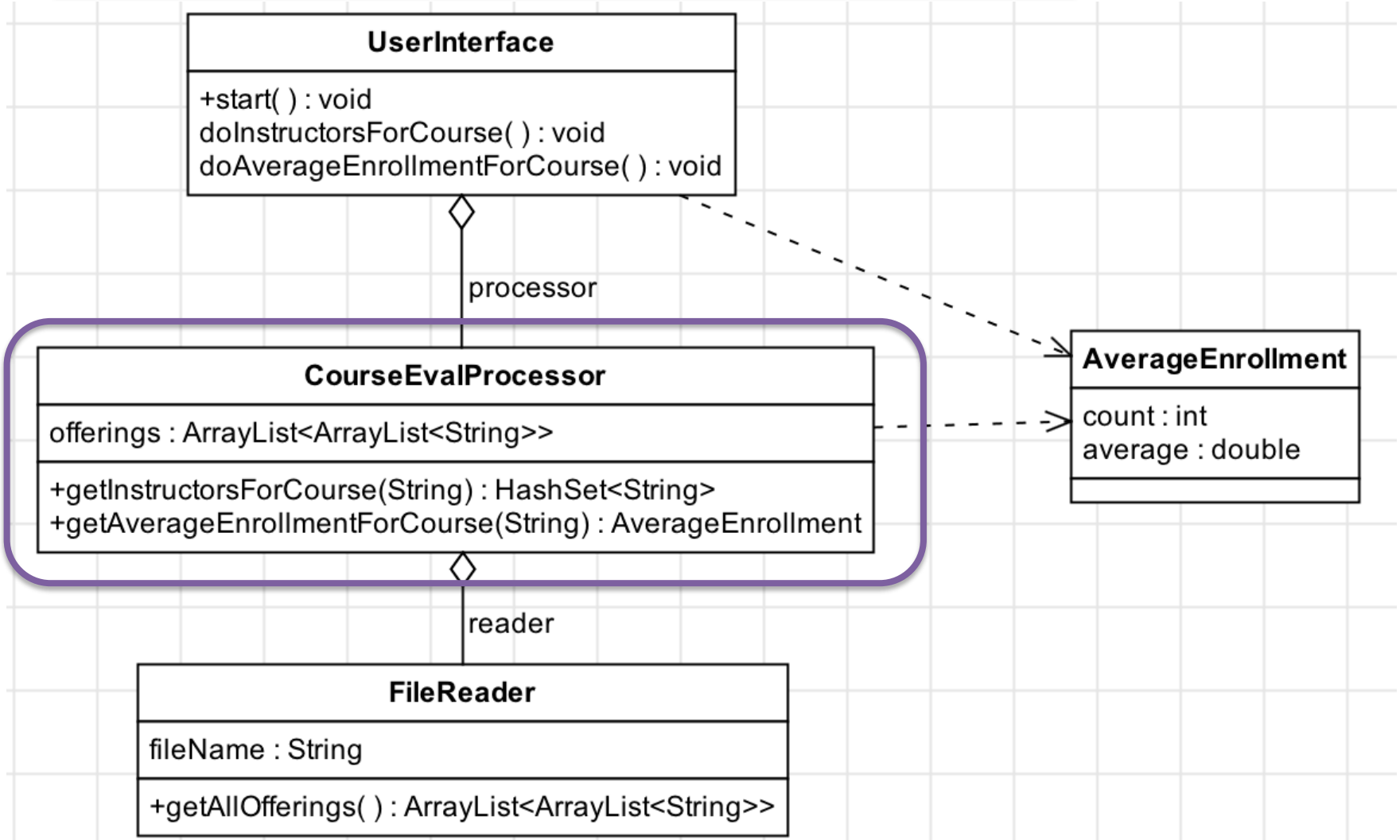


What could change? User Interface

- (Human) language used in UI
- Prompts for input
- Mechanism for input
- Format of output
- UI technology: command line, Swing, Android
- How error messages are displayed

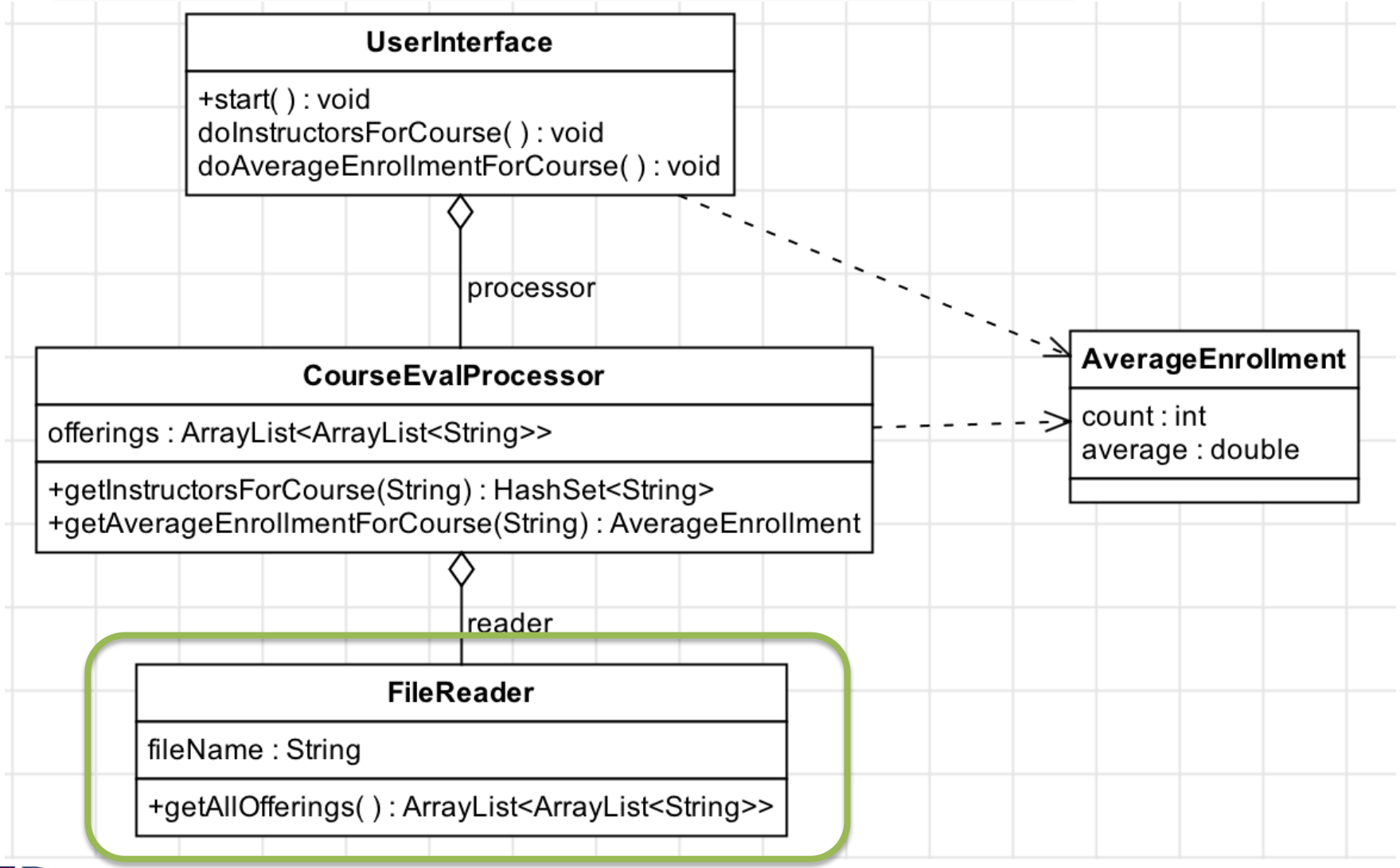
What could change?



What could change? Processor

- What we're searching
- Logic of conducting the search
- Details of the search, e.g. whether it's case-sensitive
- How errors are handled

What could change?



What could change? FileReader

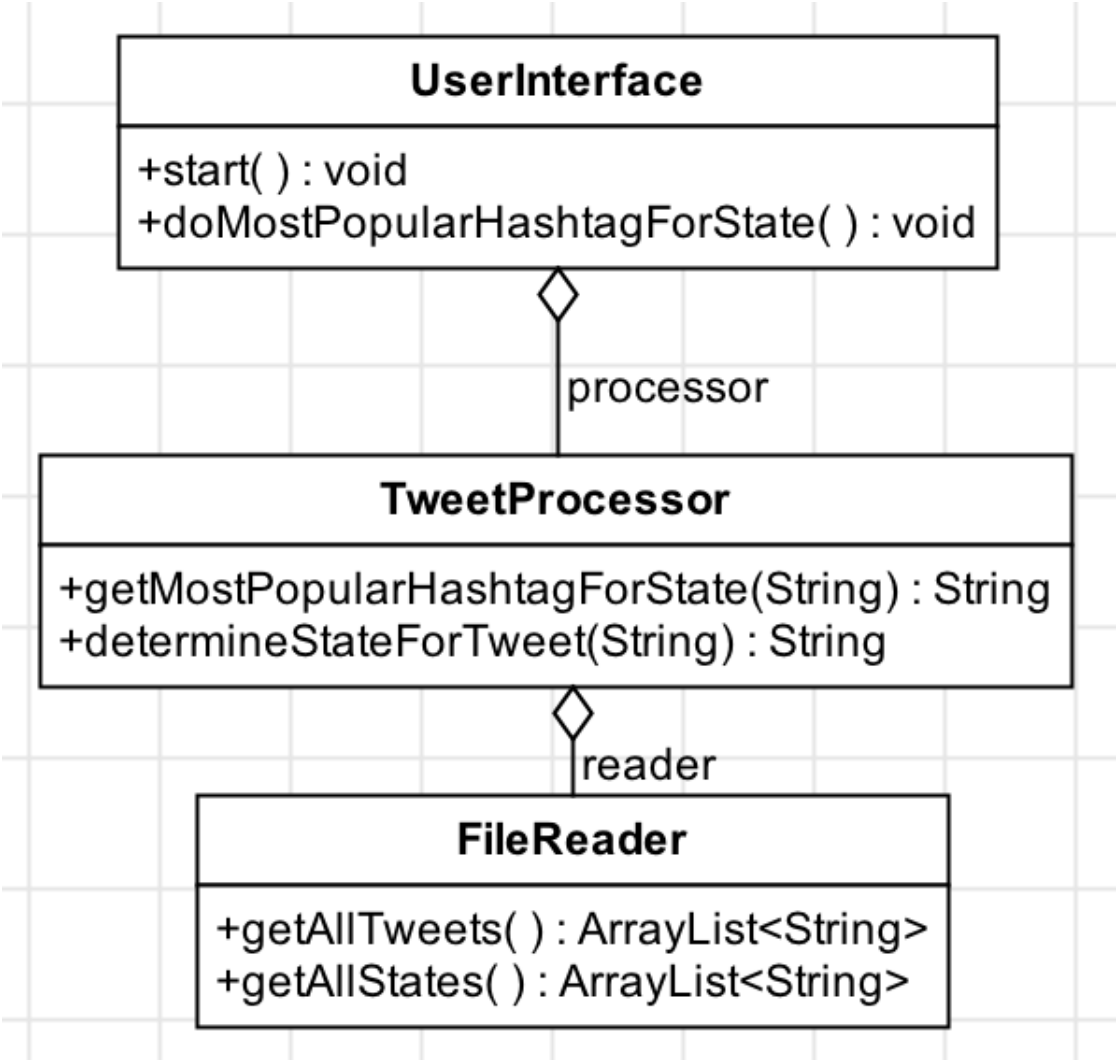
- Format of input: CSV, JSON, XML, etc.
- Layout of format: ordering of fields
- Source of input: file, database, web service
- How errors are handled

Another Motivating Example

- Design a program that reads in a file containing tweets, which include text and geolocation info

- Determine the most popular hashtag for a given U.S. state

A modular design



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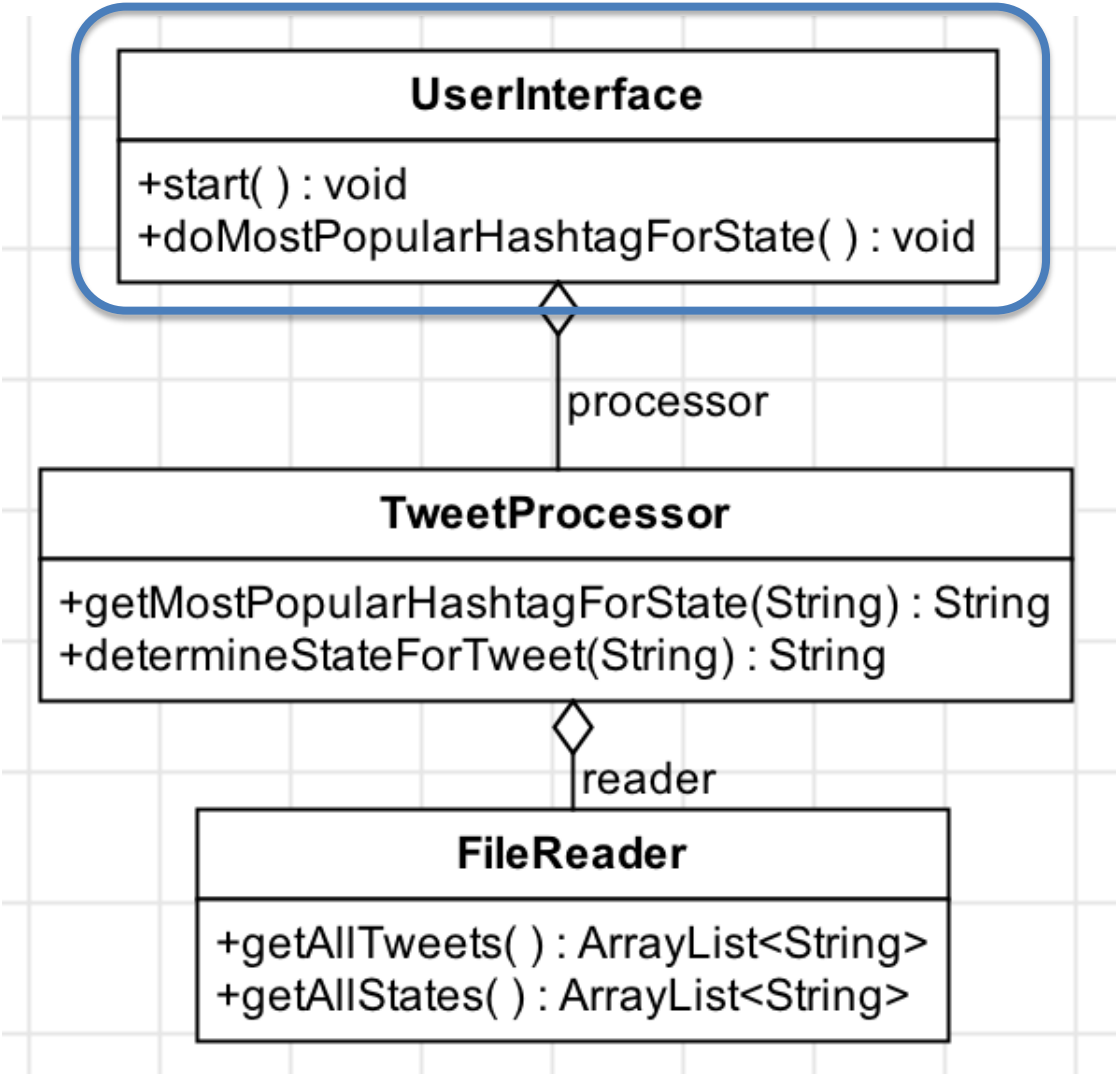

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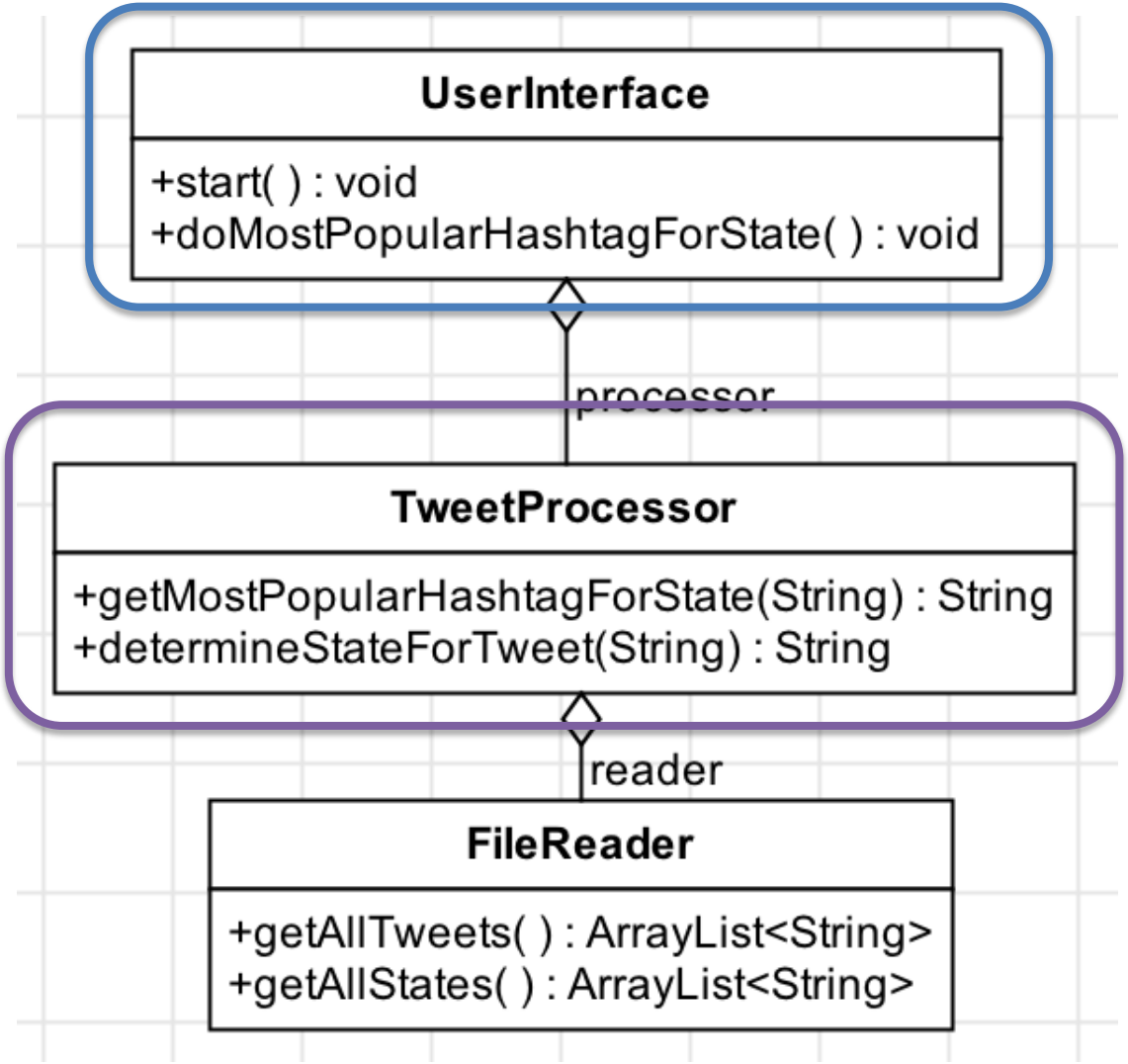

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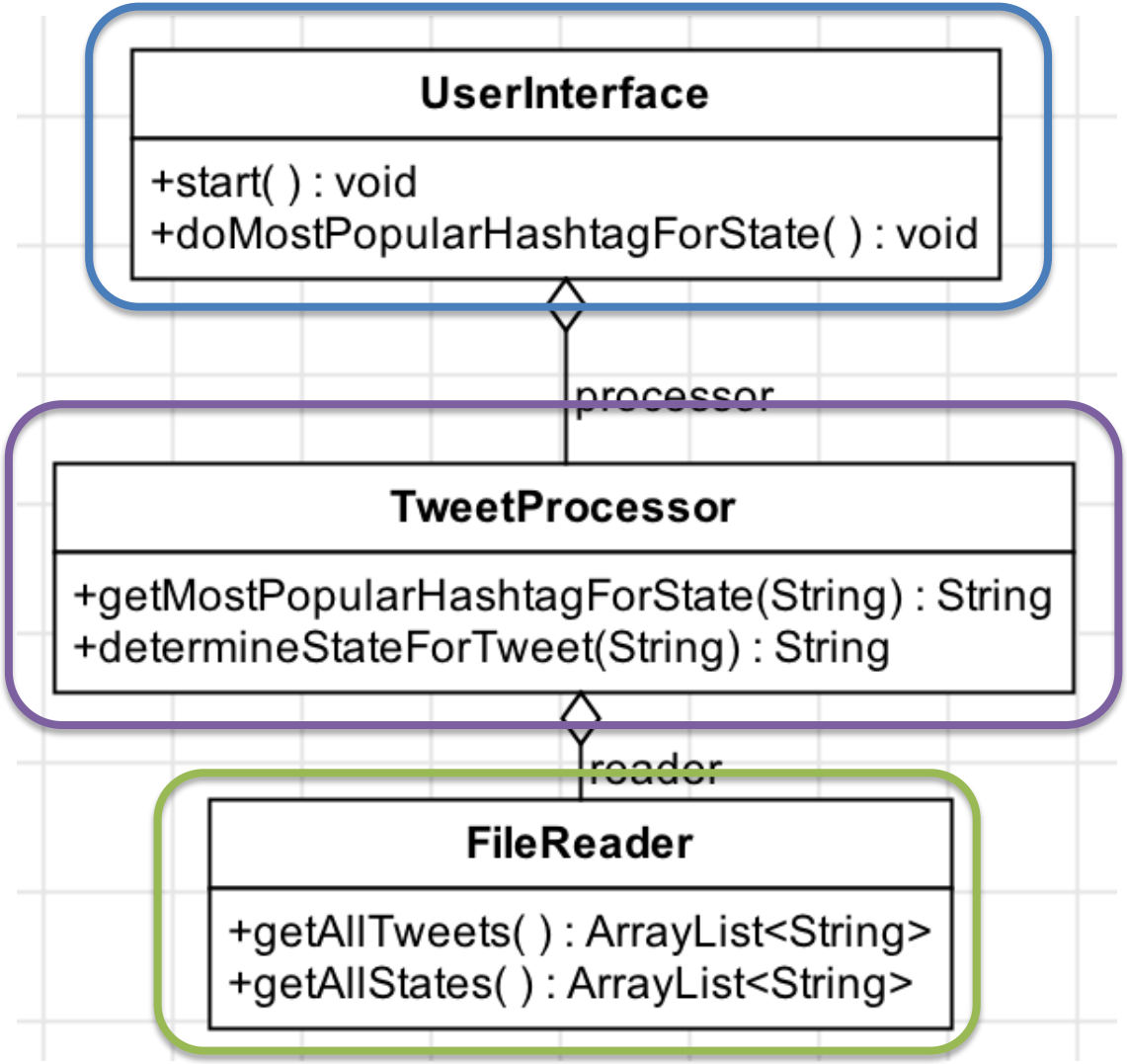
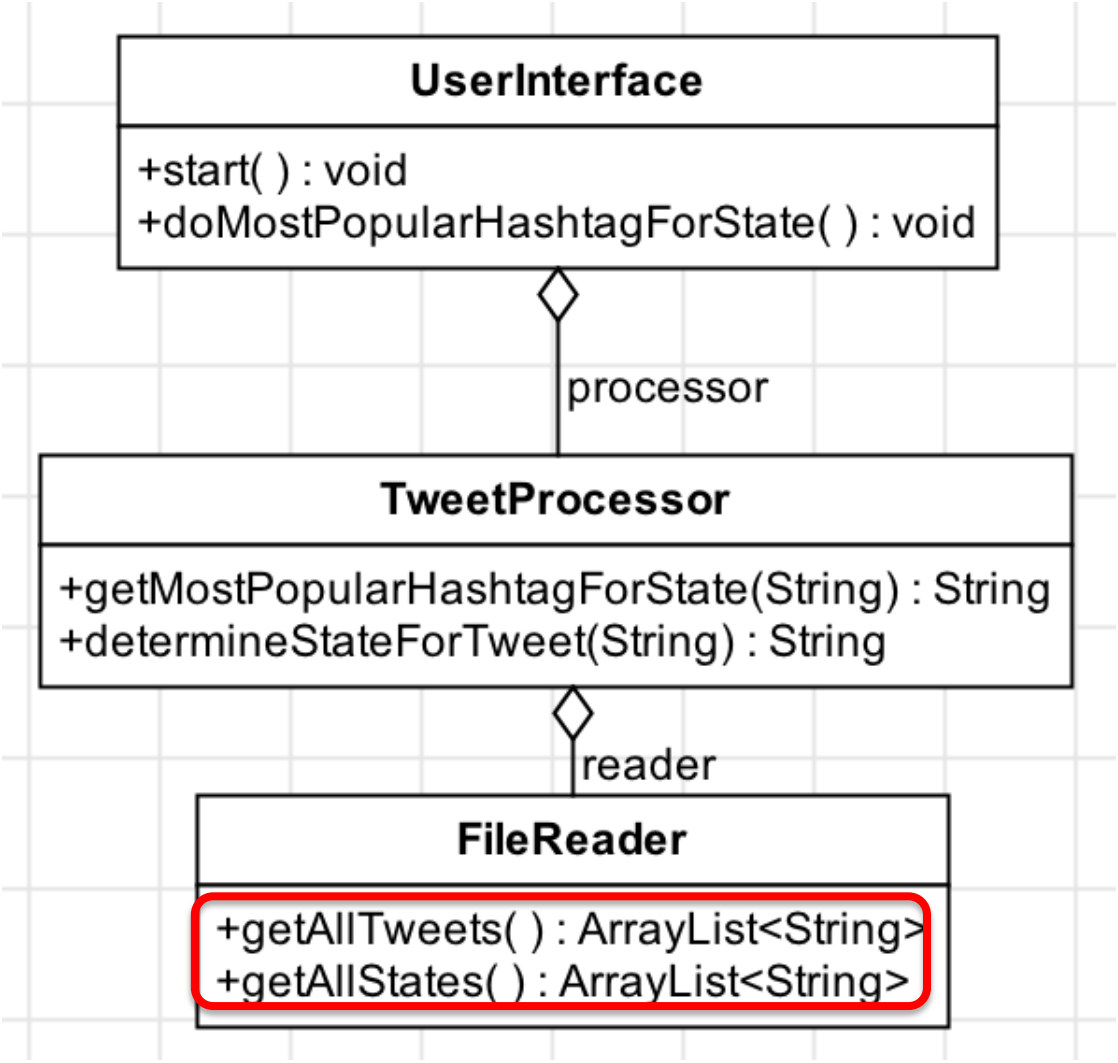
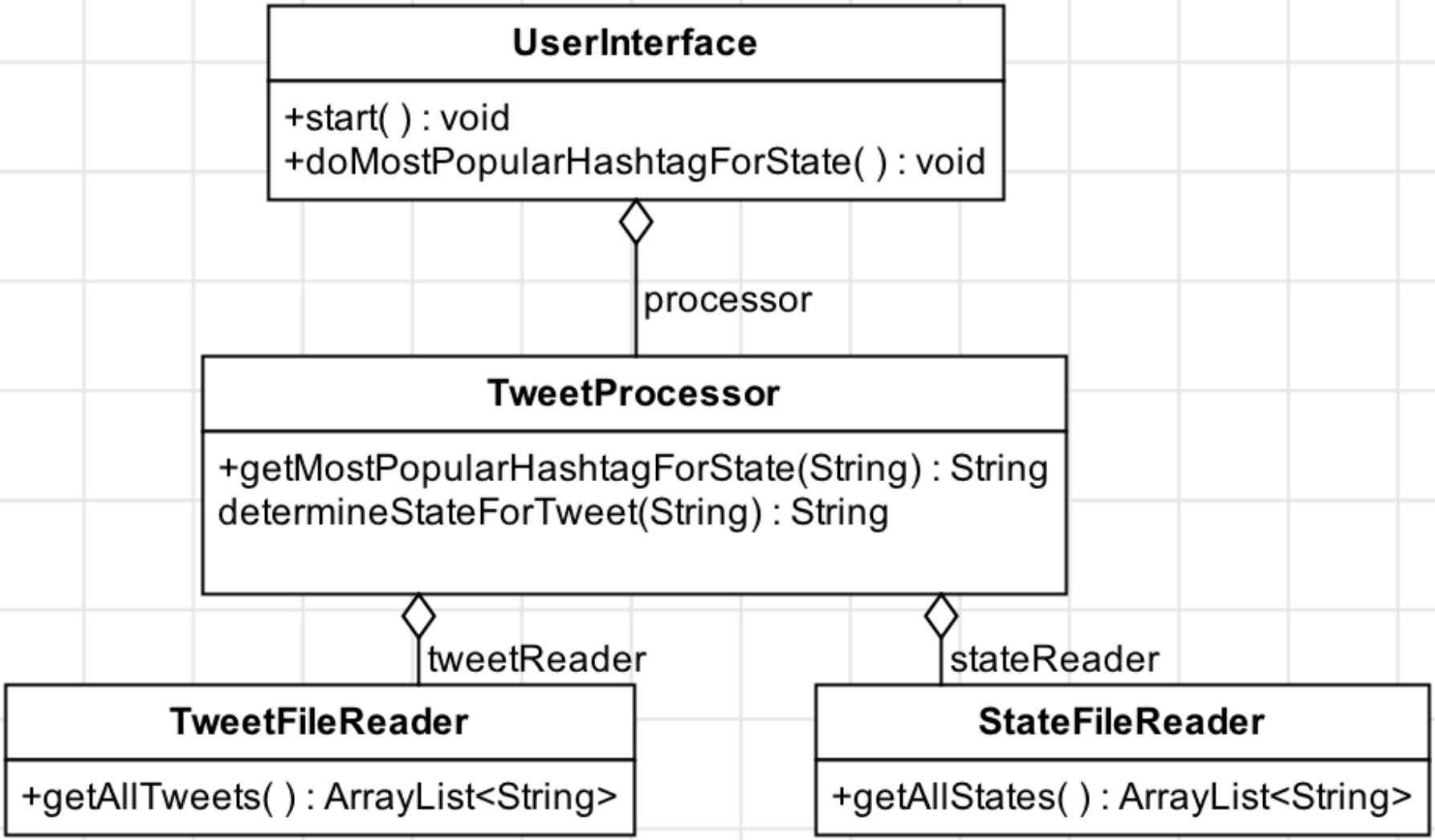


A modular design



A more modular design



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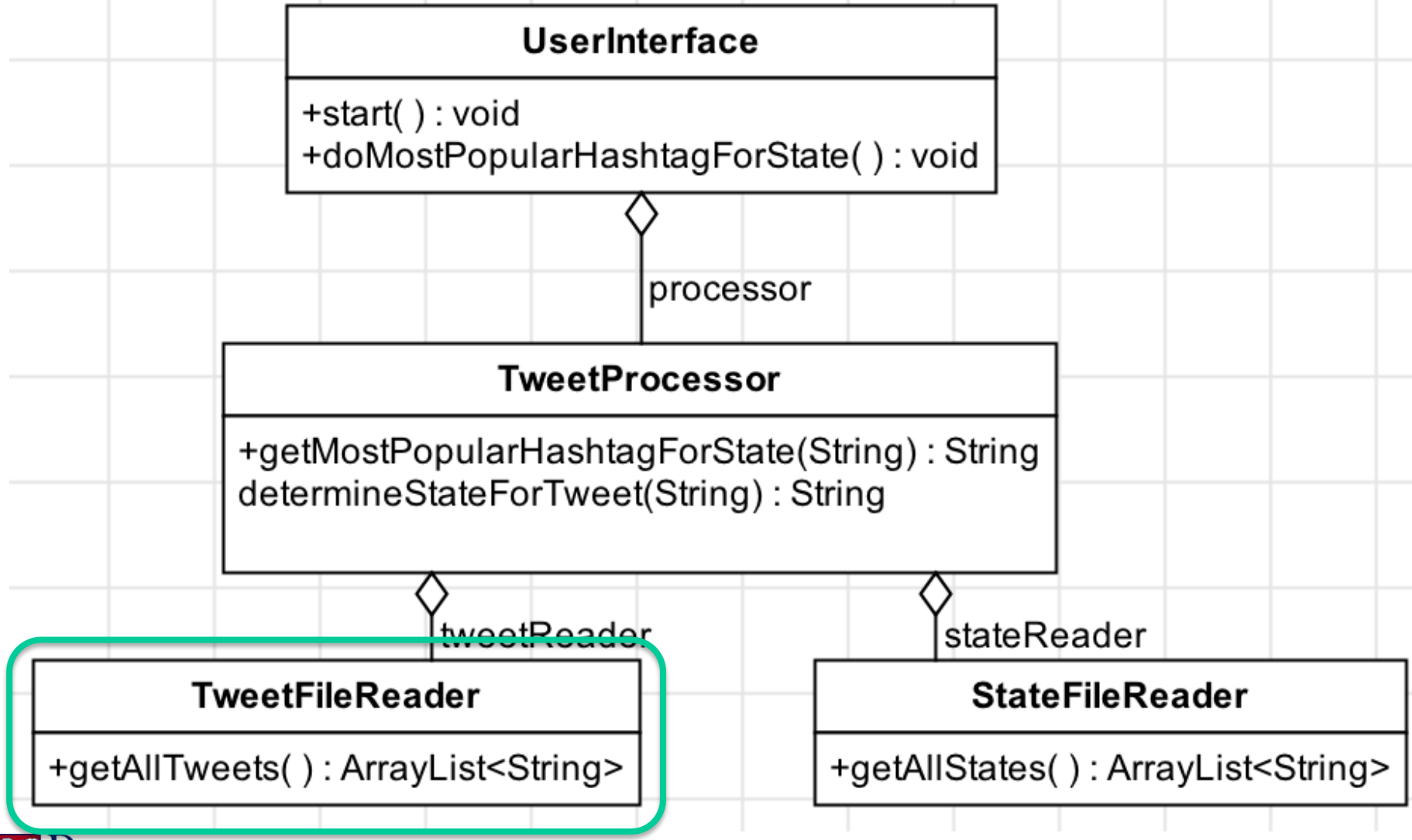

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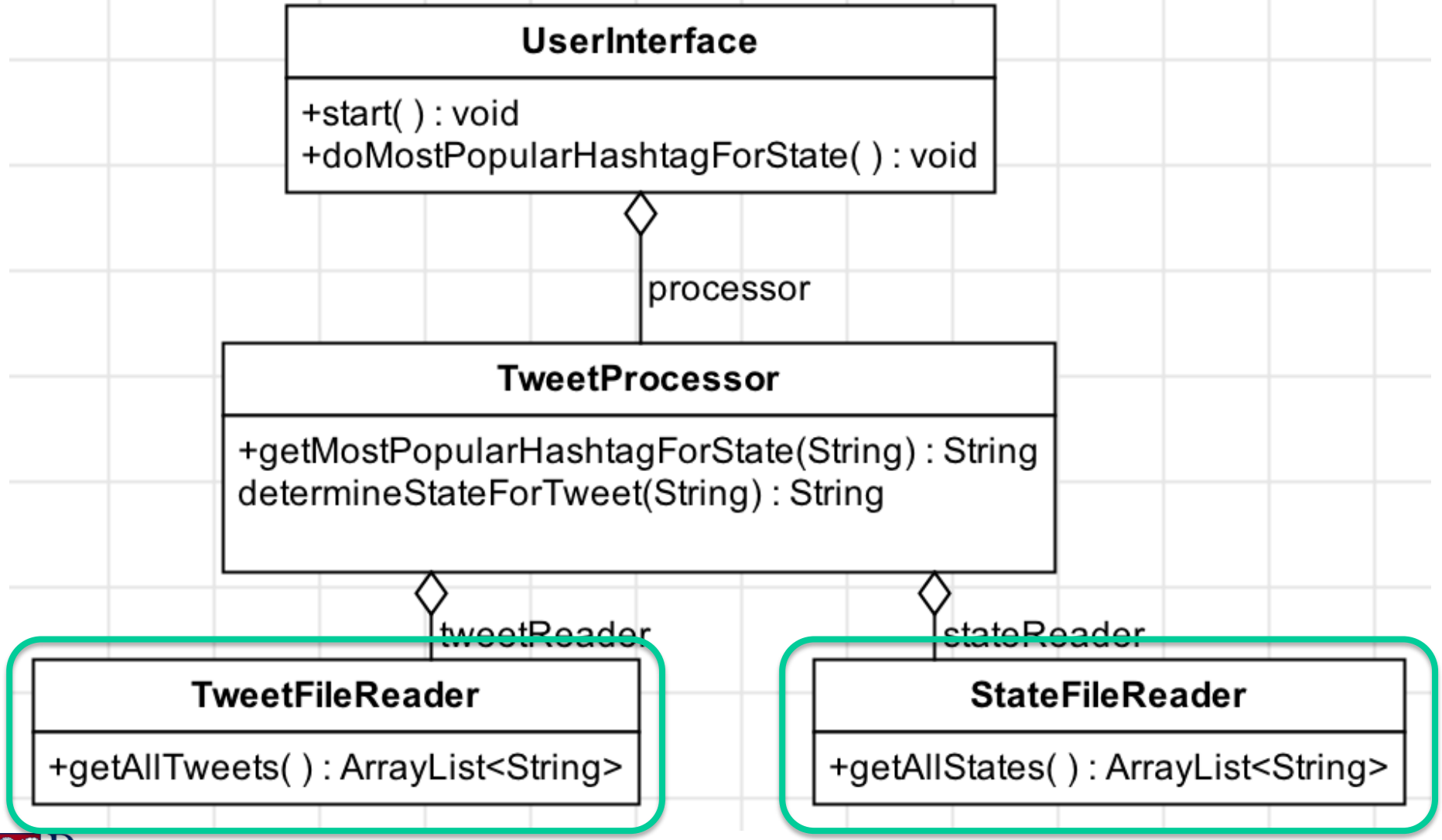

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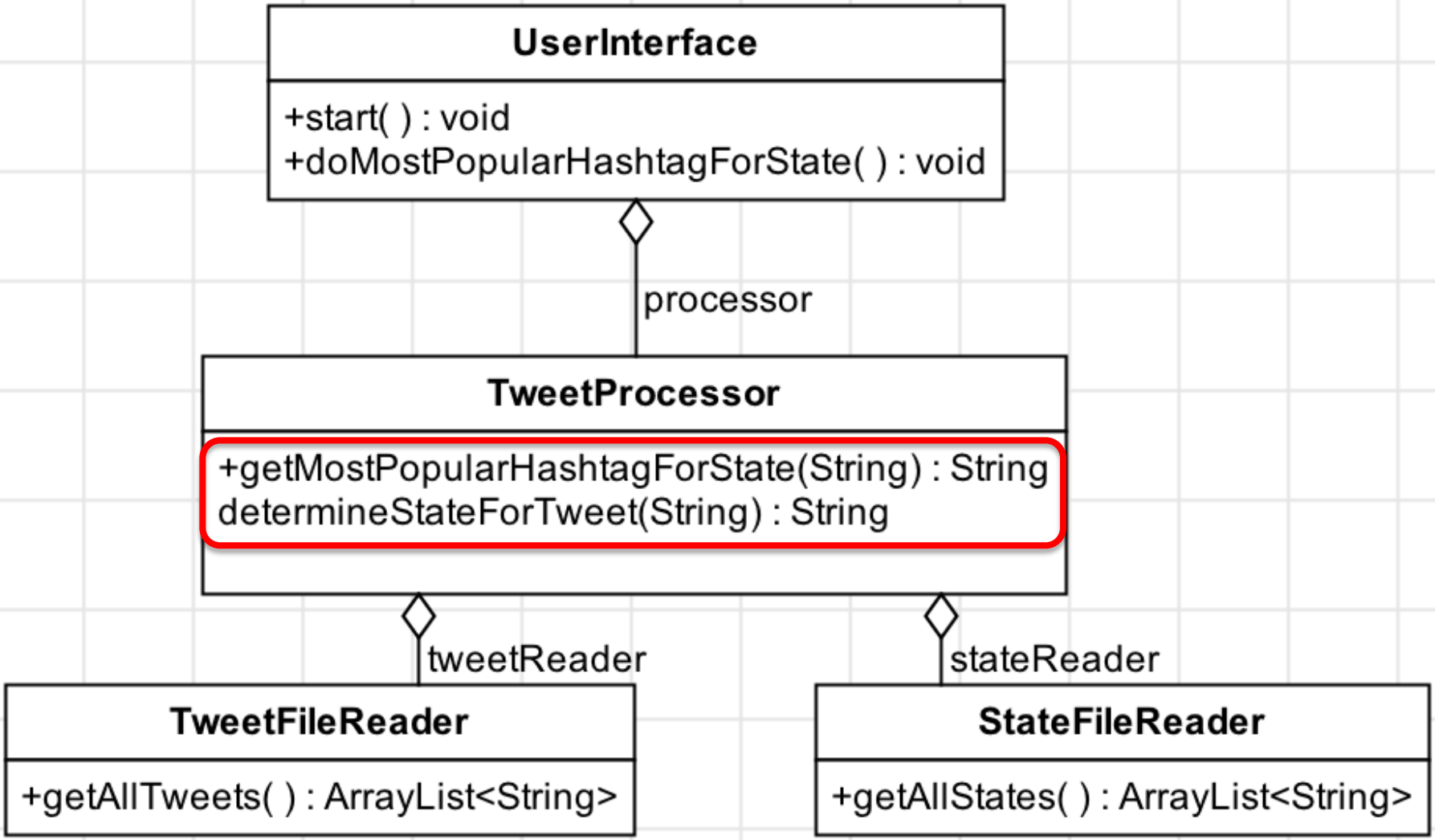

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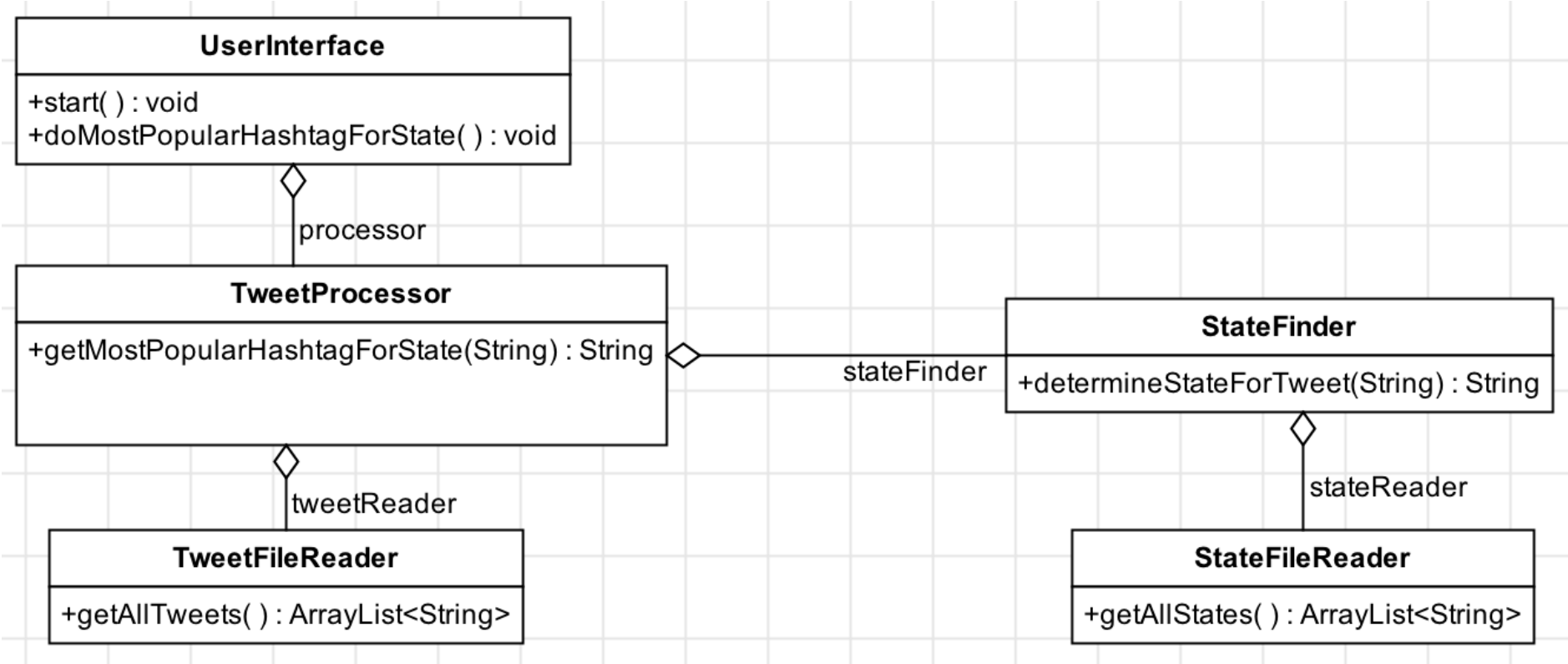

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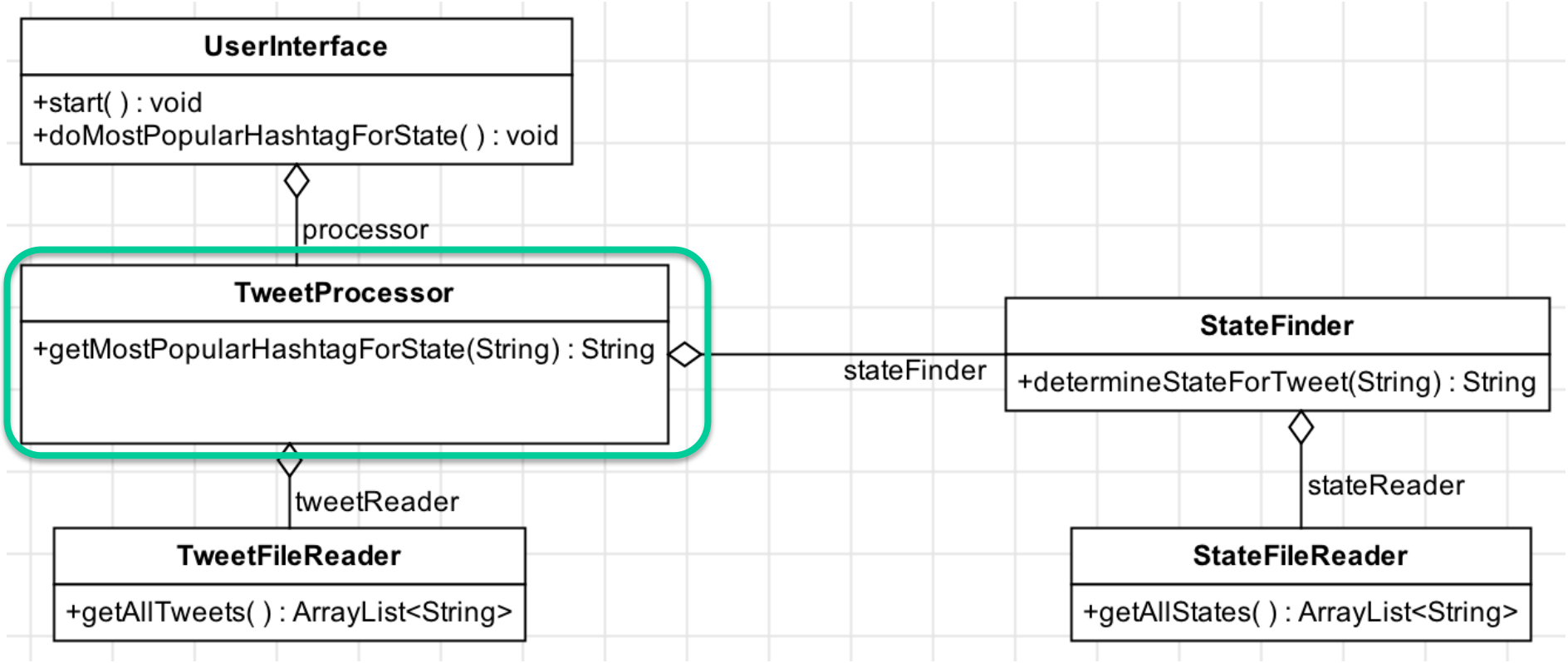

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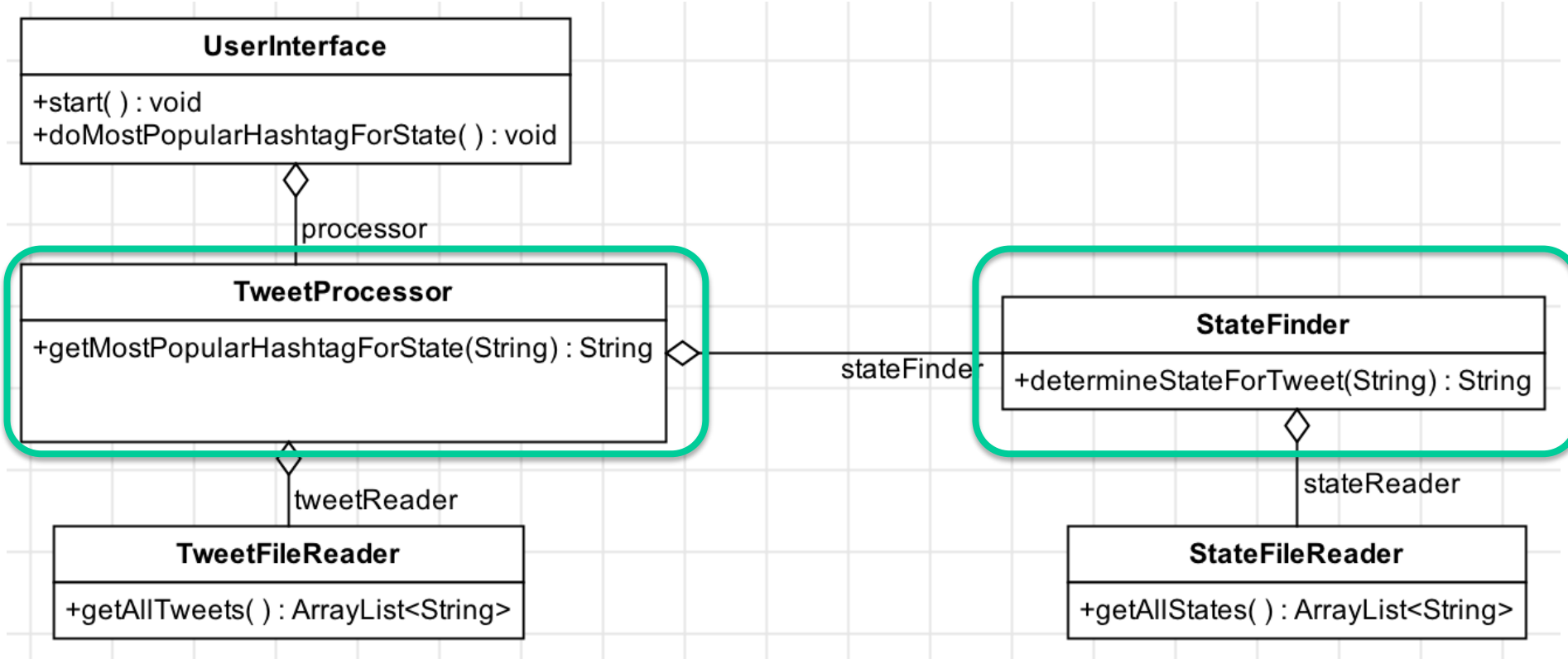
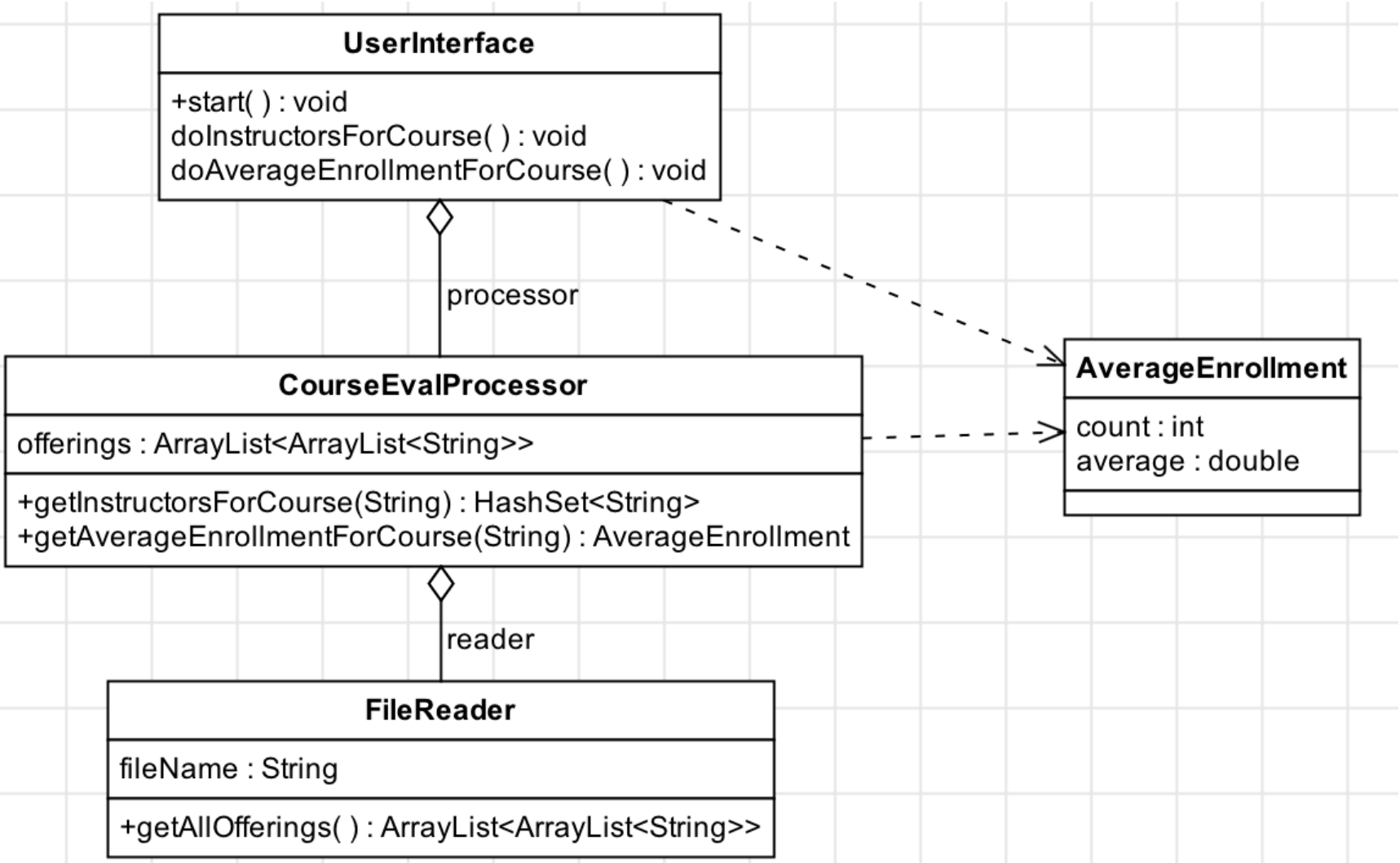


Cohesion

- The extent to which the parts of a module (class) “go together”

- All operations and attributes should contribute to a single, well-defined task

Is this cohesive?



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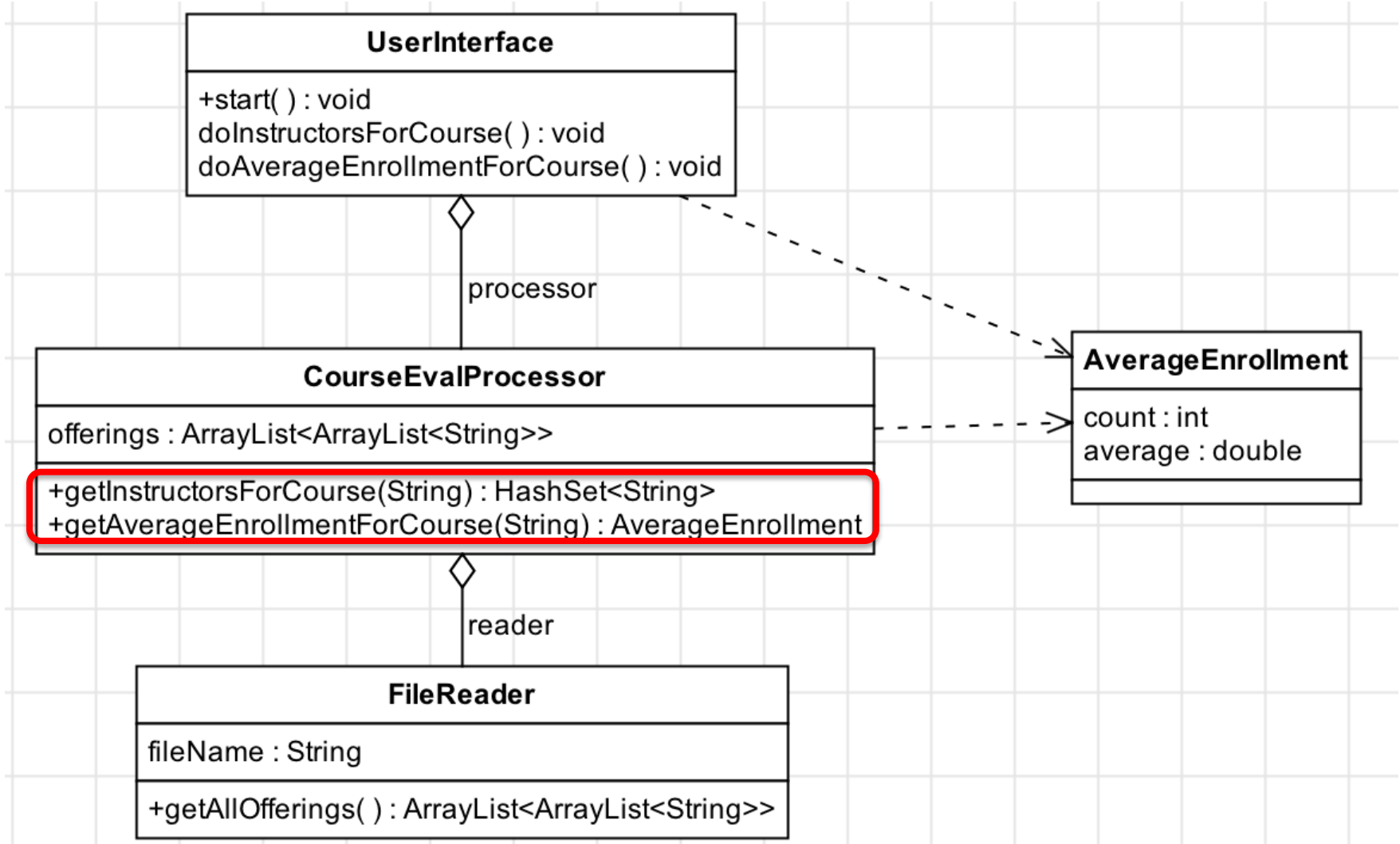
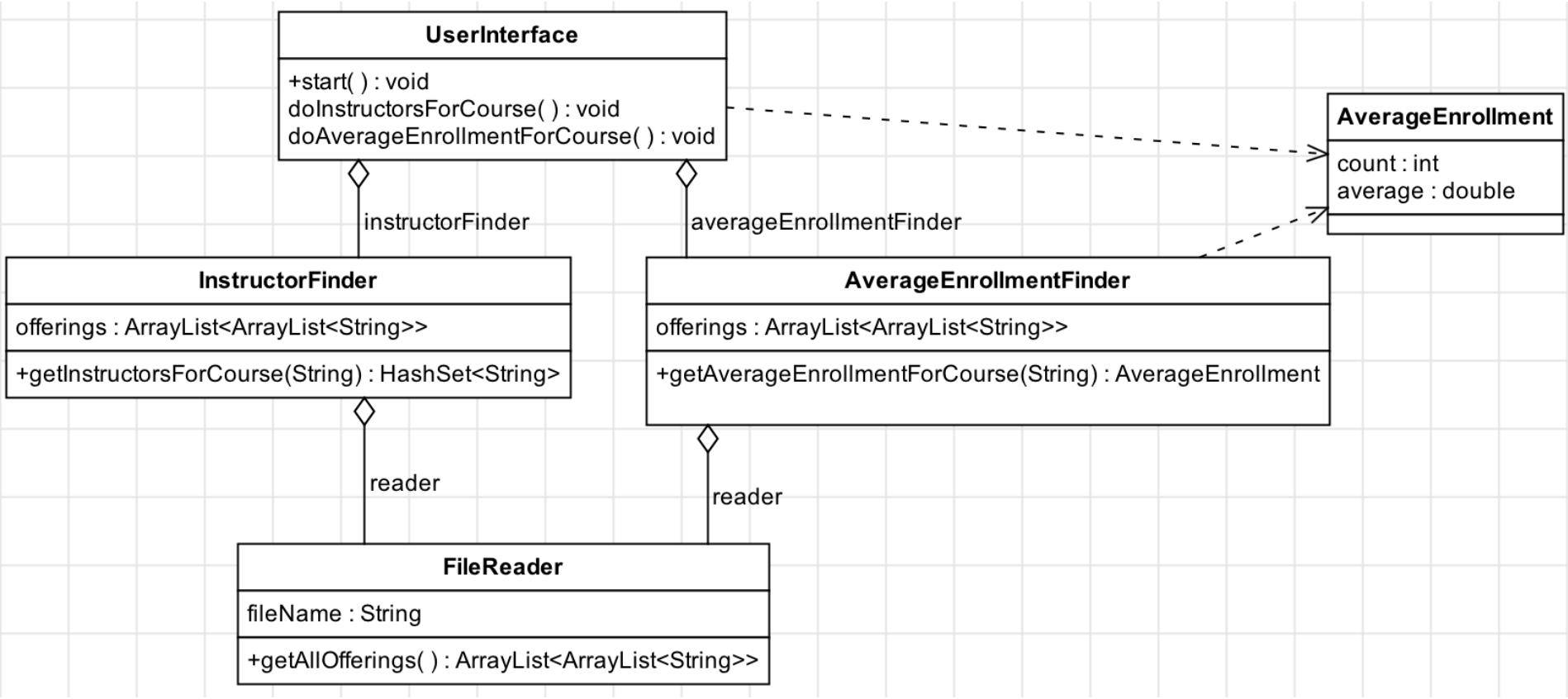


Is this too much modularity?



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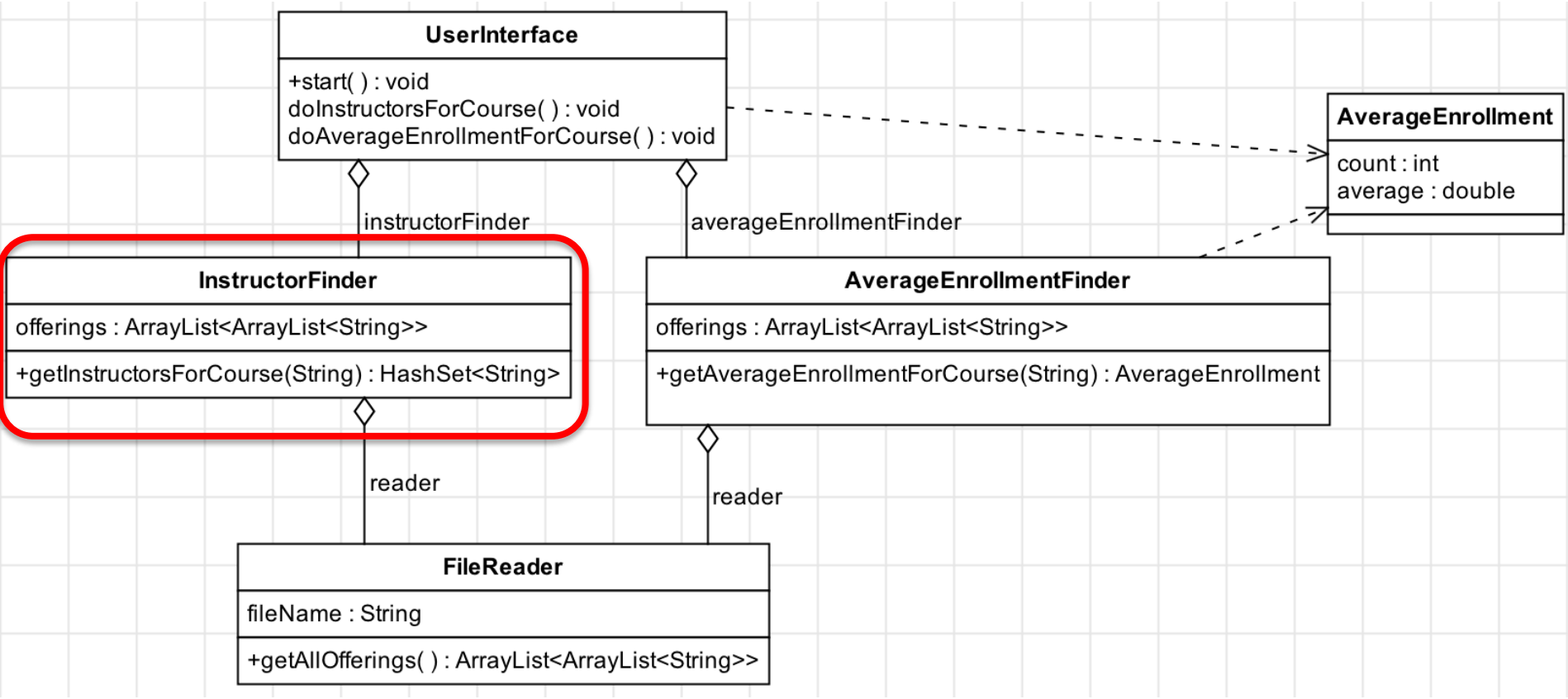

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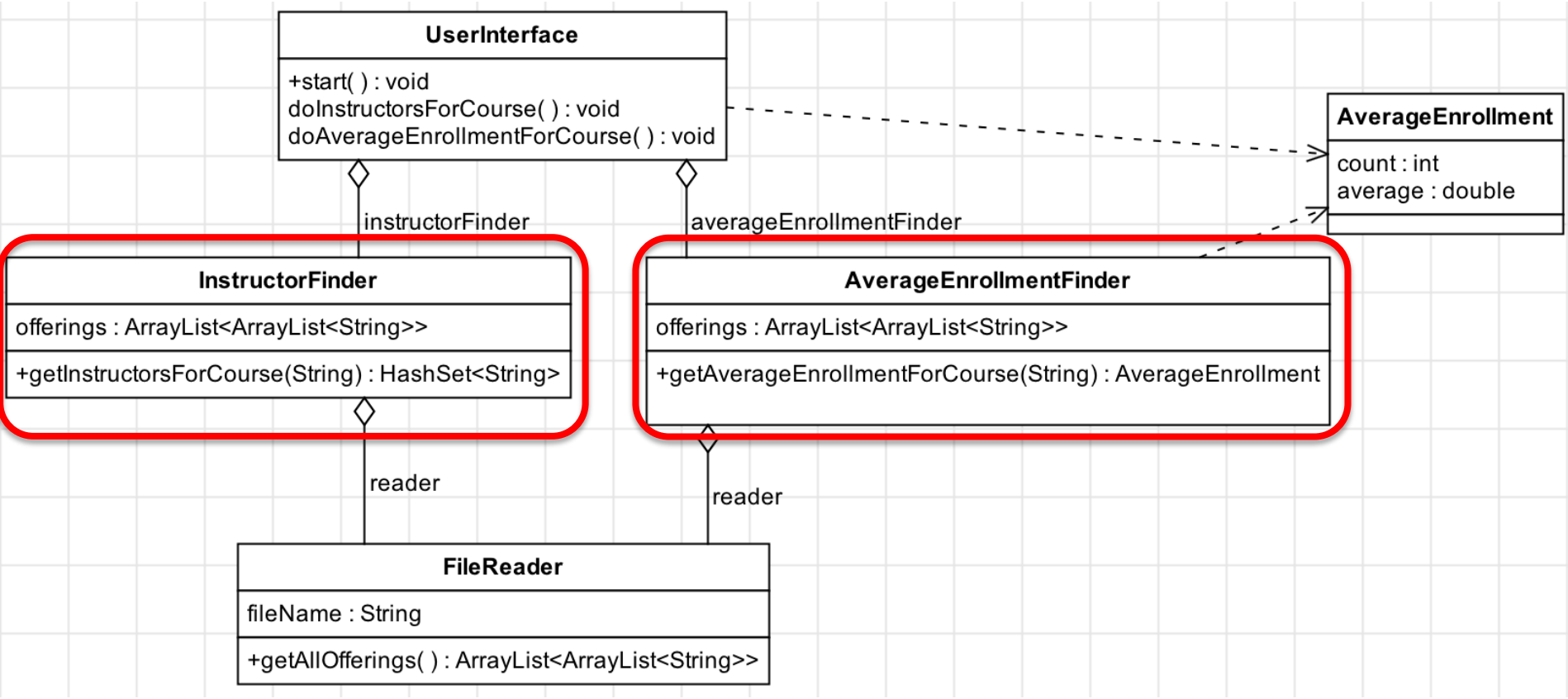
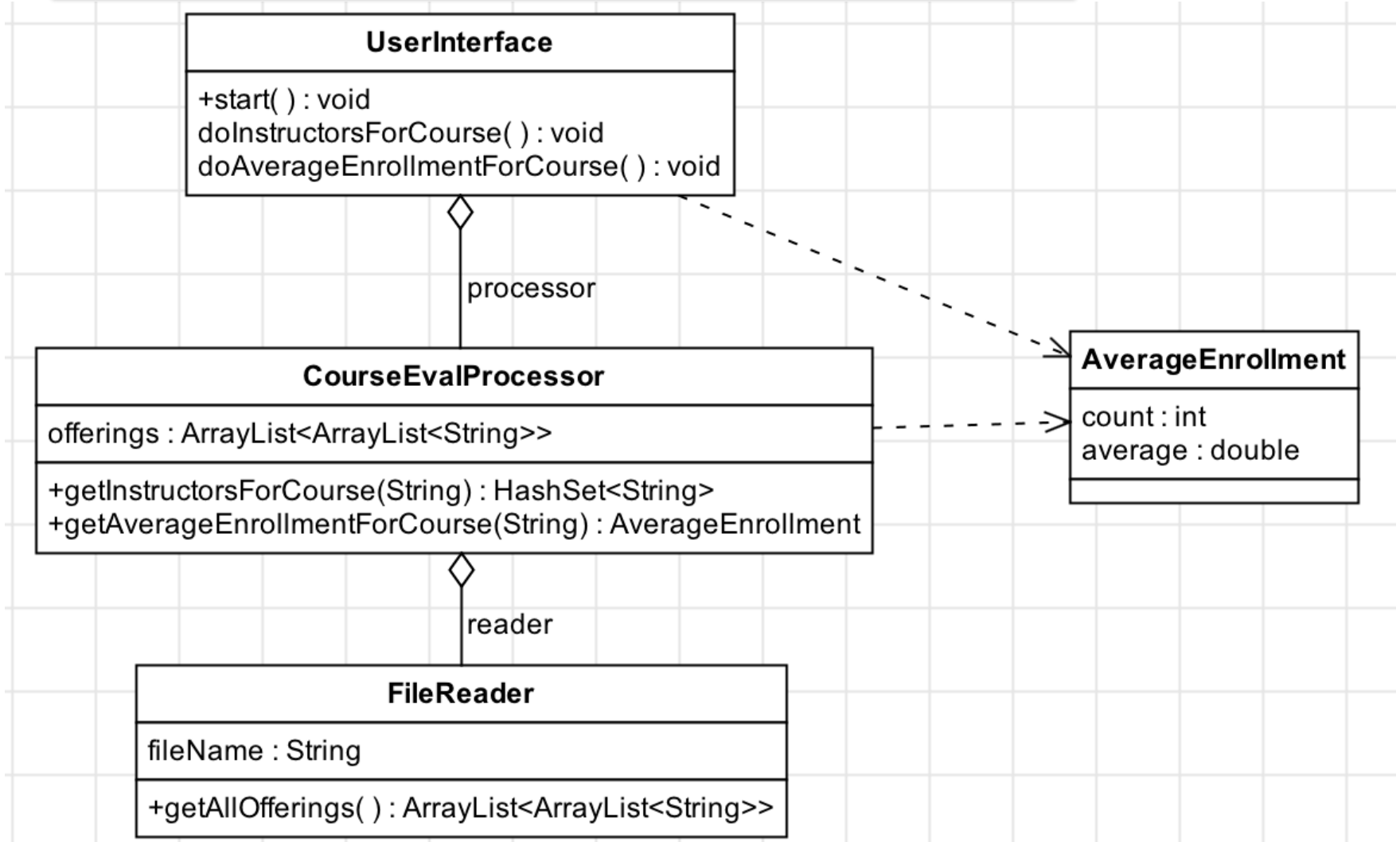


A cohesive, modular design



Recap: Modularity

- Each component (“module”) addresses a single part of the functionality
- Improves analyzability, testability, and **changeability**
- Cohesion: the extent to which the parts of a module “go together”

SD2x3.8

Functional Independence

Chris

Software Design Concepts

Modularity

Functional Independence

Abstraction

Software Design Concepts

Modularity

Functional Independence

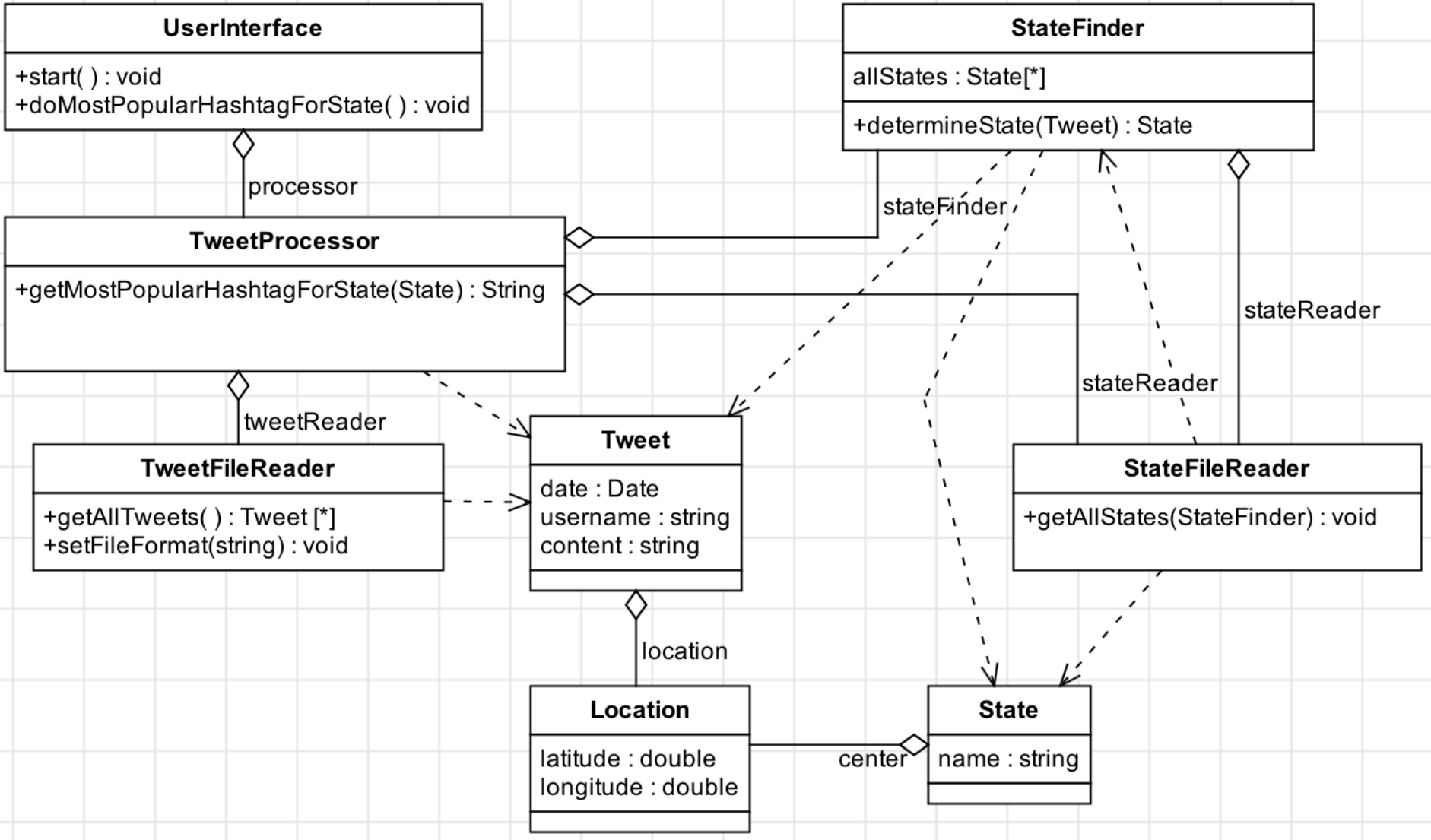
Abstraction

Motivating Example

- Design a program that reads in a file containing tweets, which include text and geolocation info

- Determine the most popular hashtag for a given U.S. state

A Modular Design



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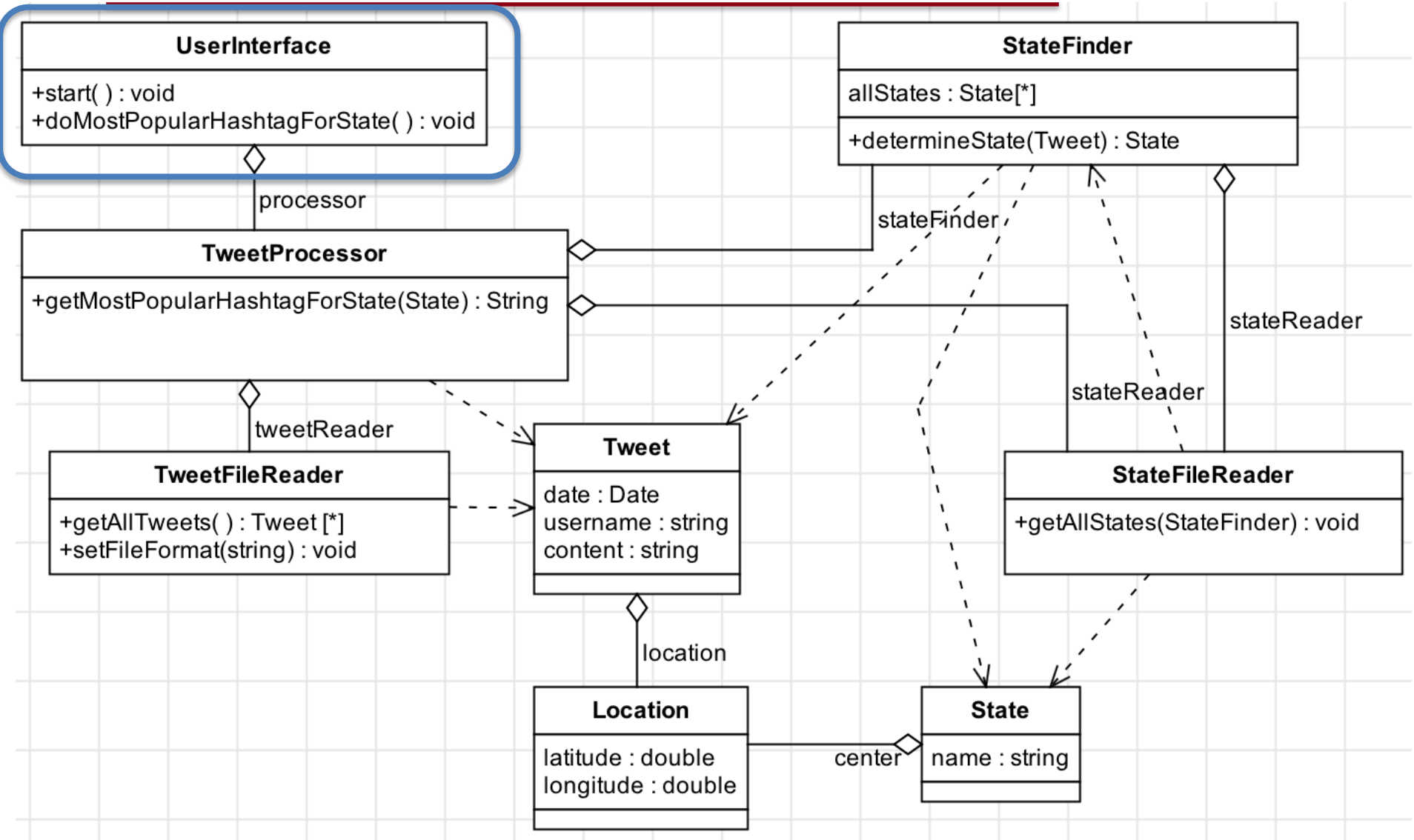
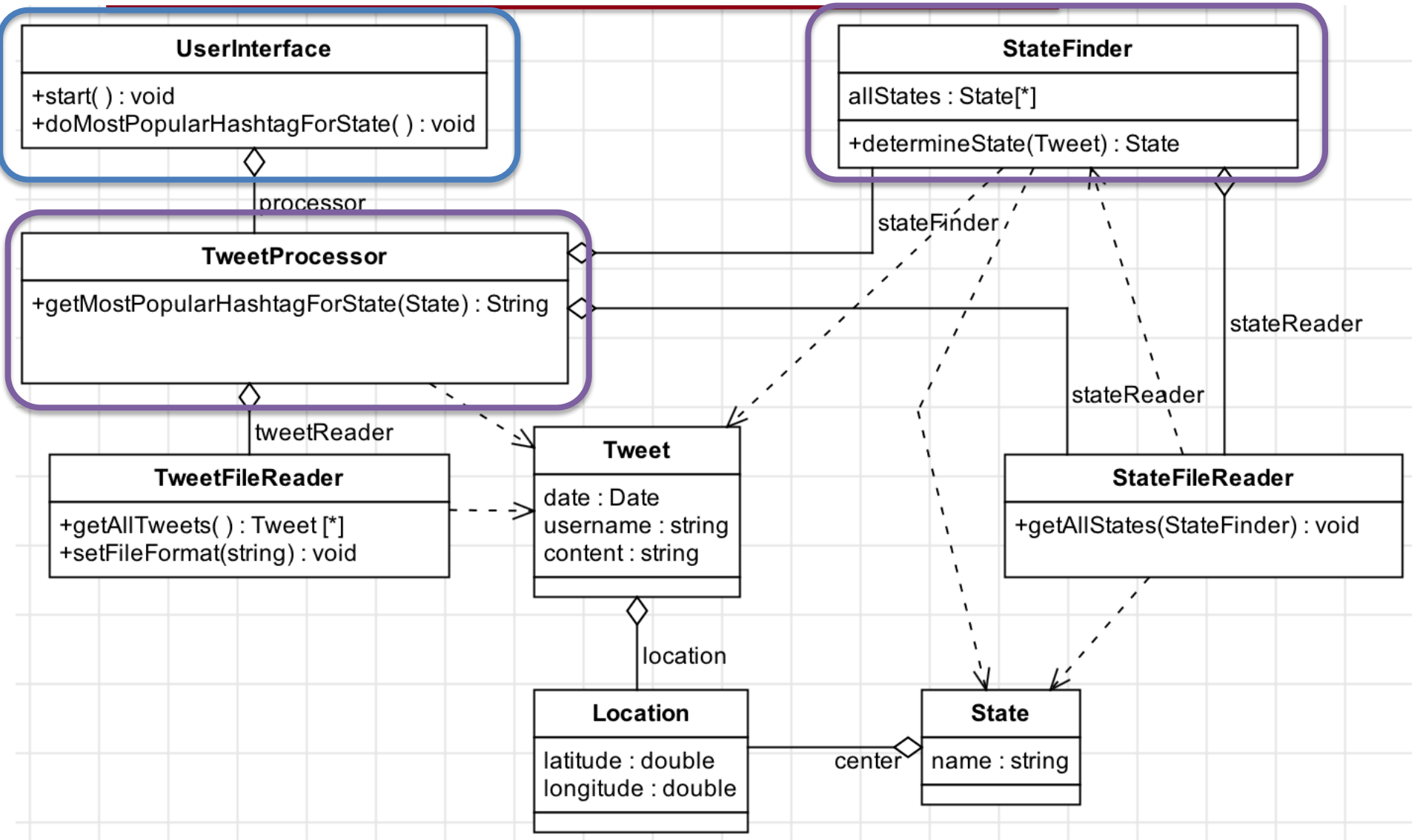


A Modular Design



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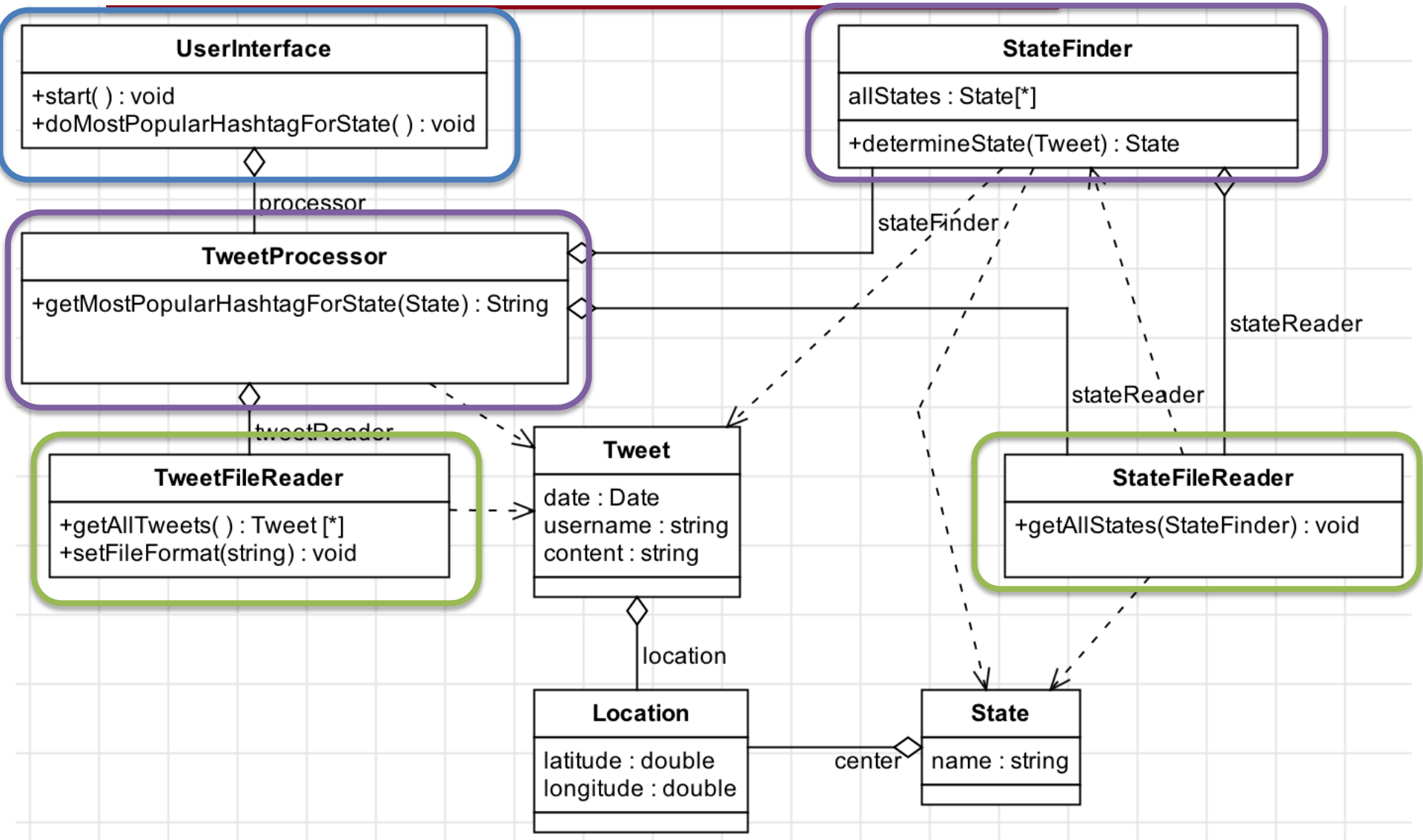


Functional Independence

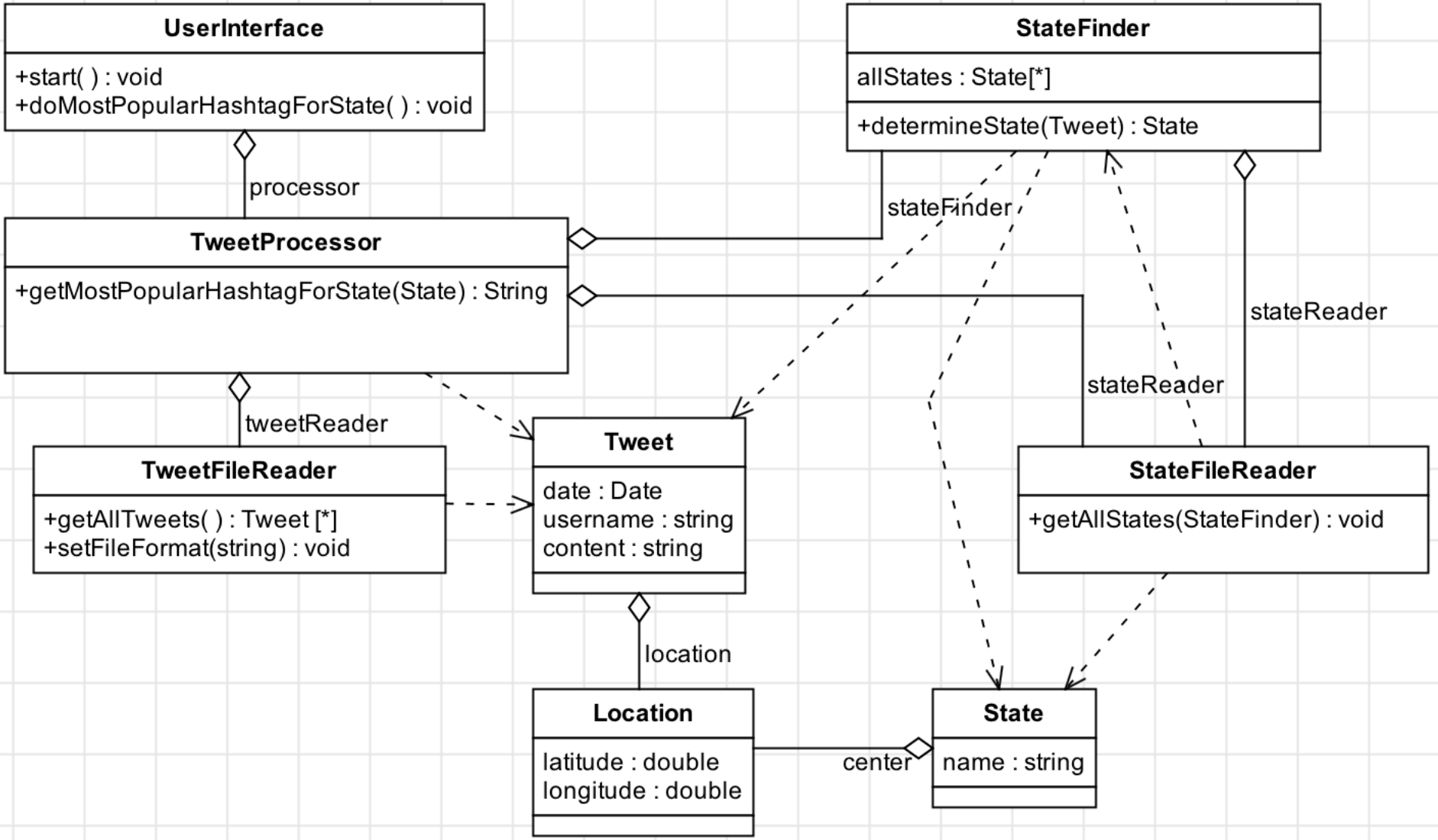
- A module should be able to do its work with minimal dependence on other modules

- Try to minimize the **number** and **complexity** of interfaces between modules

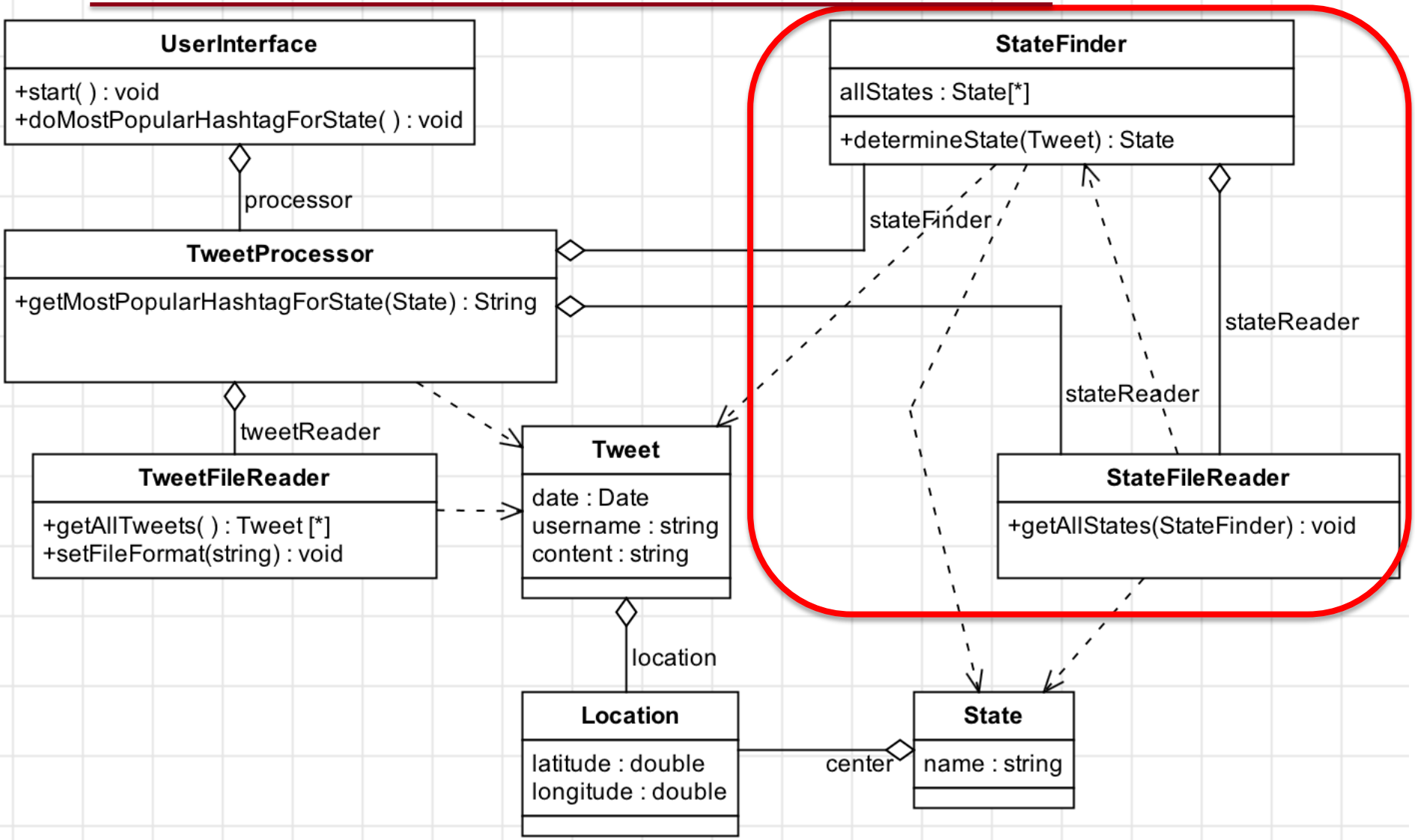
Why Functional Independence?

- **Analyzability:** easier to understand a module without having to look at other code
- **Testability:** permits testing of a module independent from other modules
- **“Reusability”:** pieces of code can be reused without need their dependencies
- **Changeability/Stability:** can change code without needing to change the things that depend on it

Are these modules independent?



Cyclic Dependencies: BAD!



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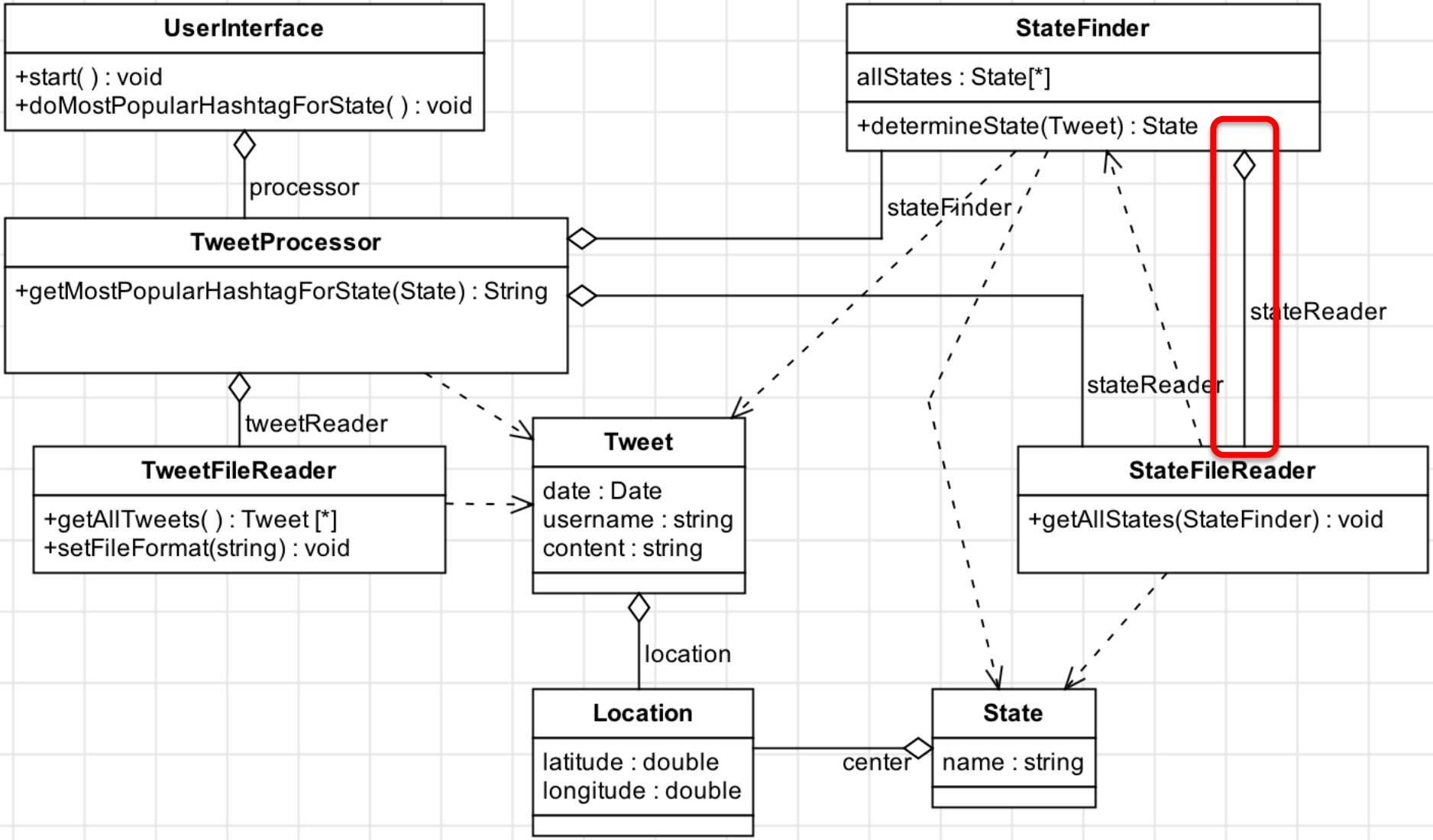

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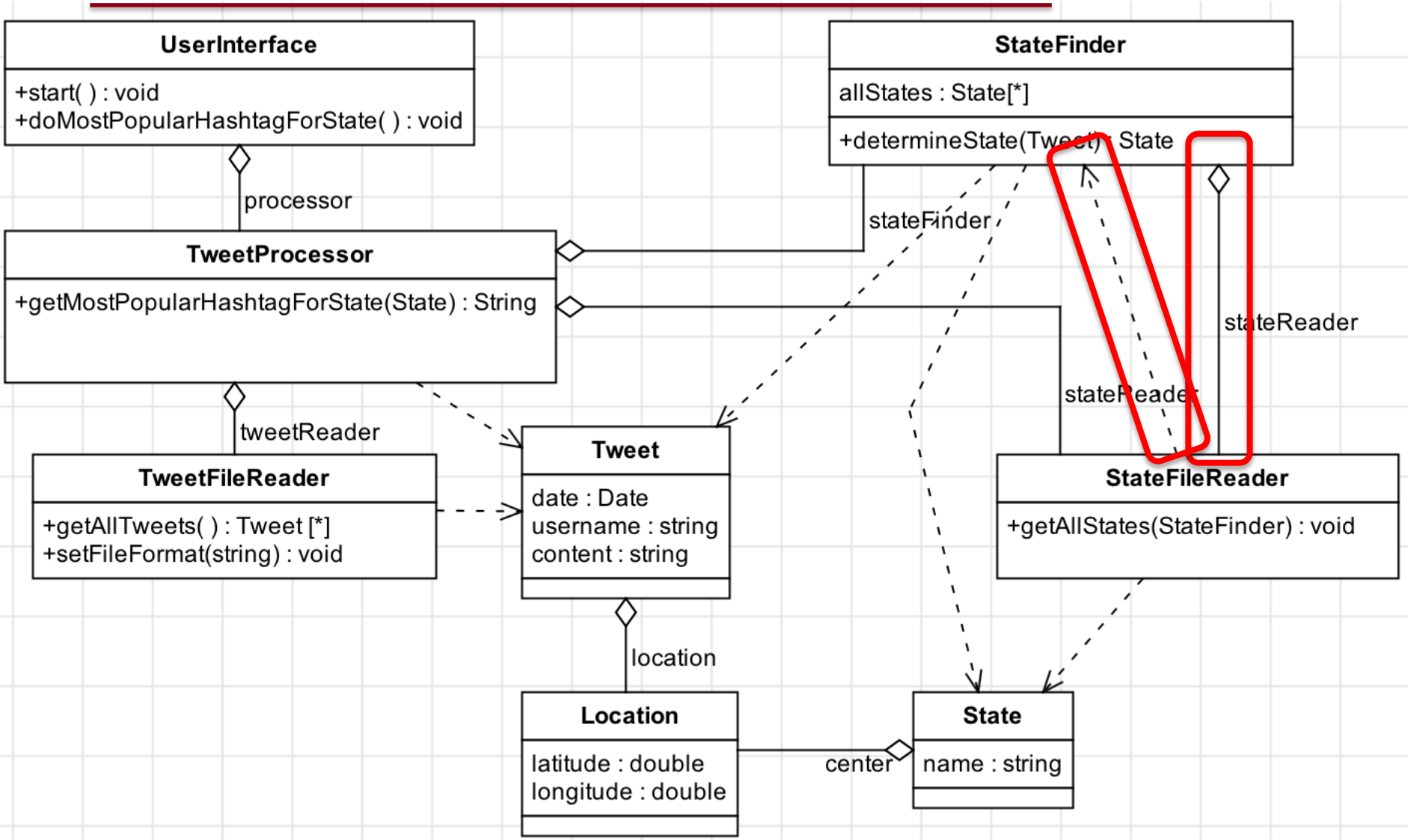

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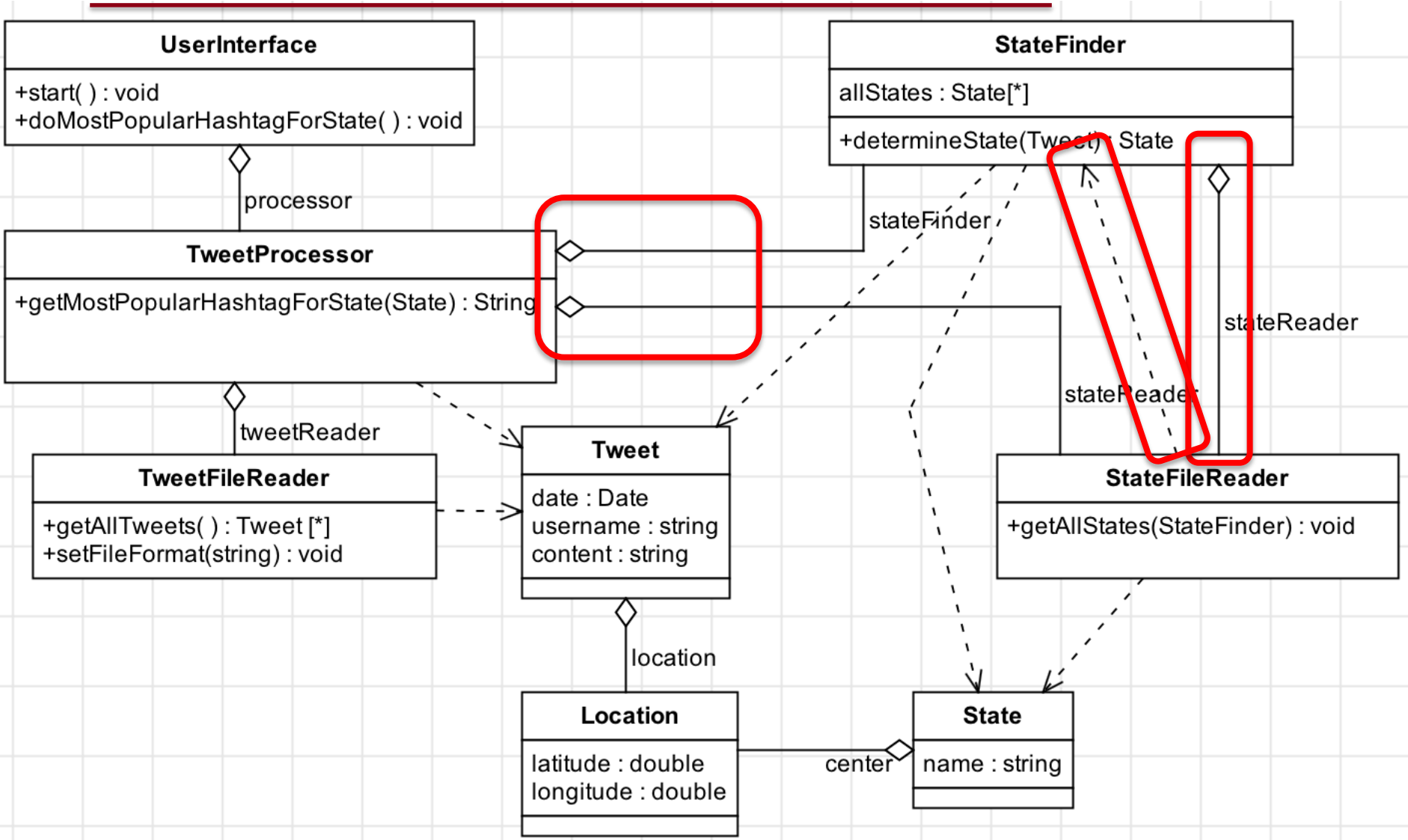

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public class TweetProcessor {
    protected StateFinder stateFinder;
    protected StateFileReader stateFileReader;

    public TweetProcessor() {
        stateFinder = new StateFinder();
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        stateFileReader.getAllStates(stateFinder);
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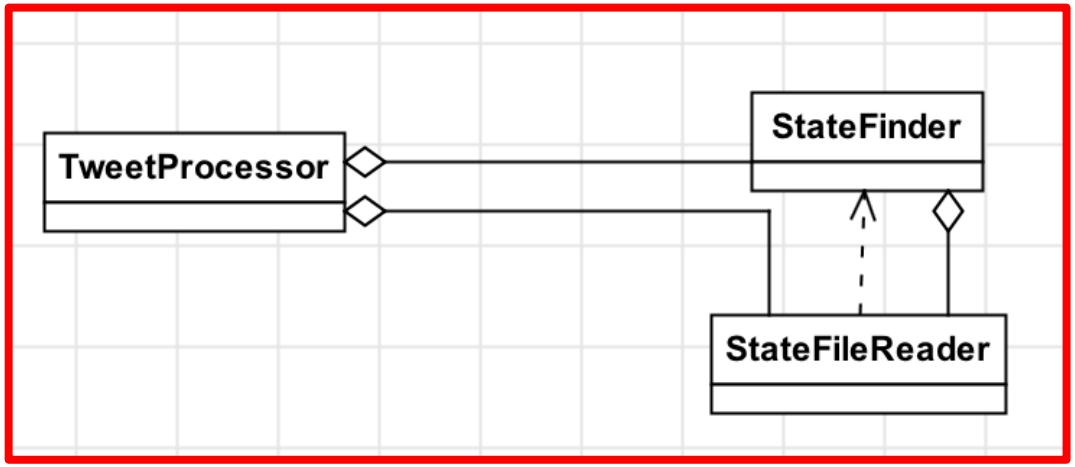

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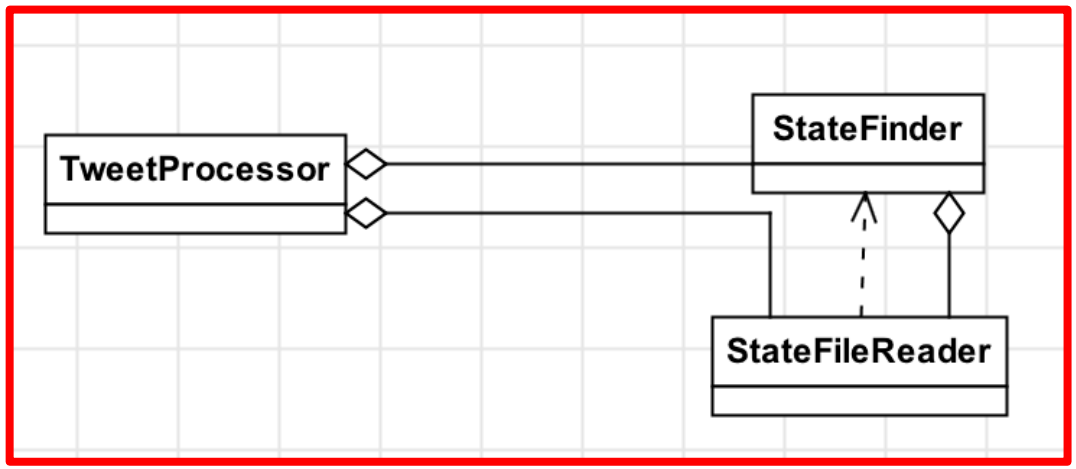

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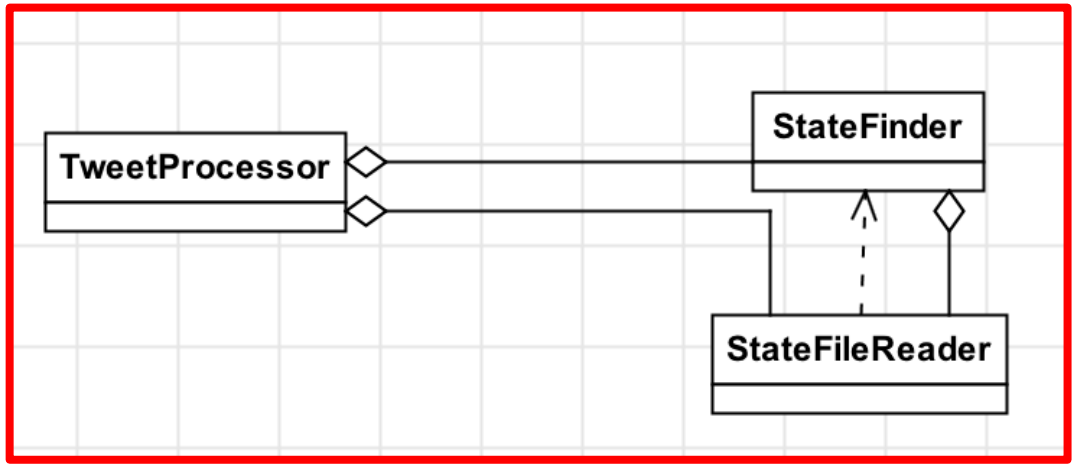

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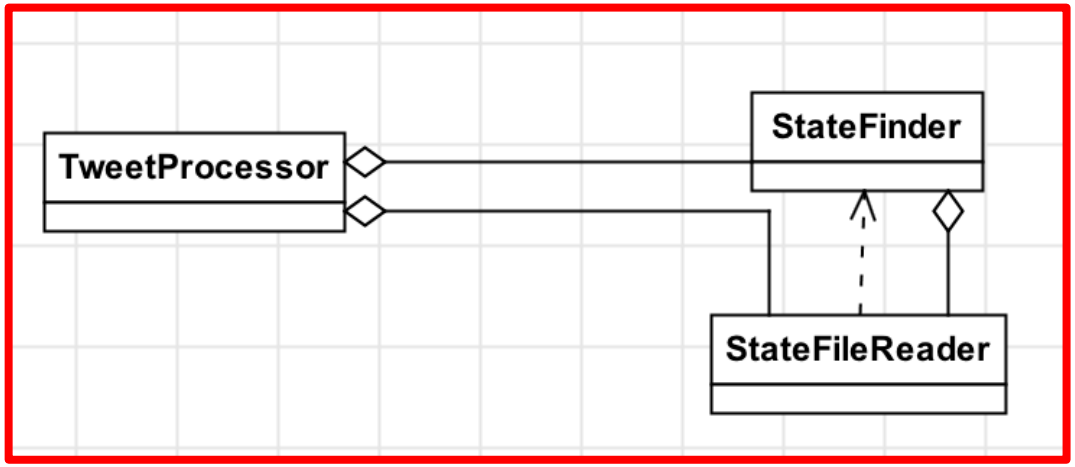

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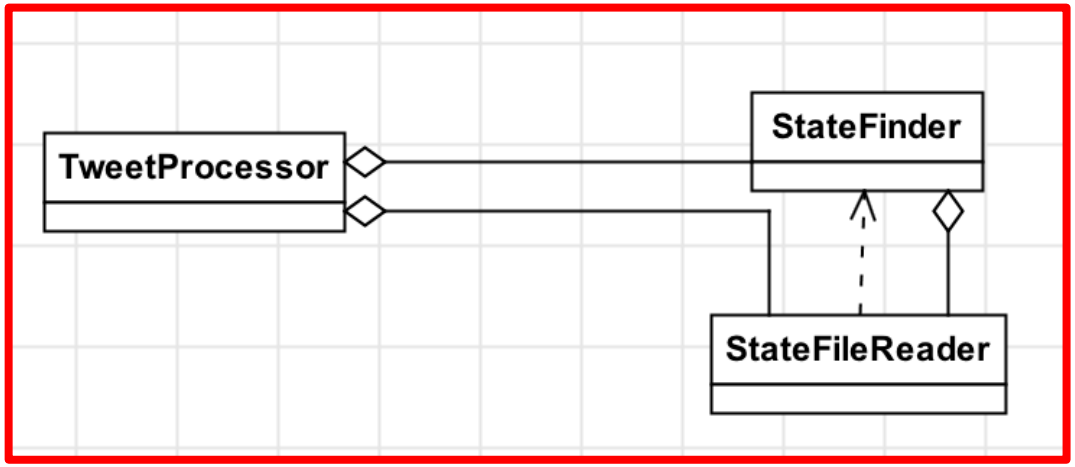

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    public void getAllStates(StateFinder finder) {
        State[] states = . . .
        finder.allStates = states;
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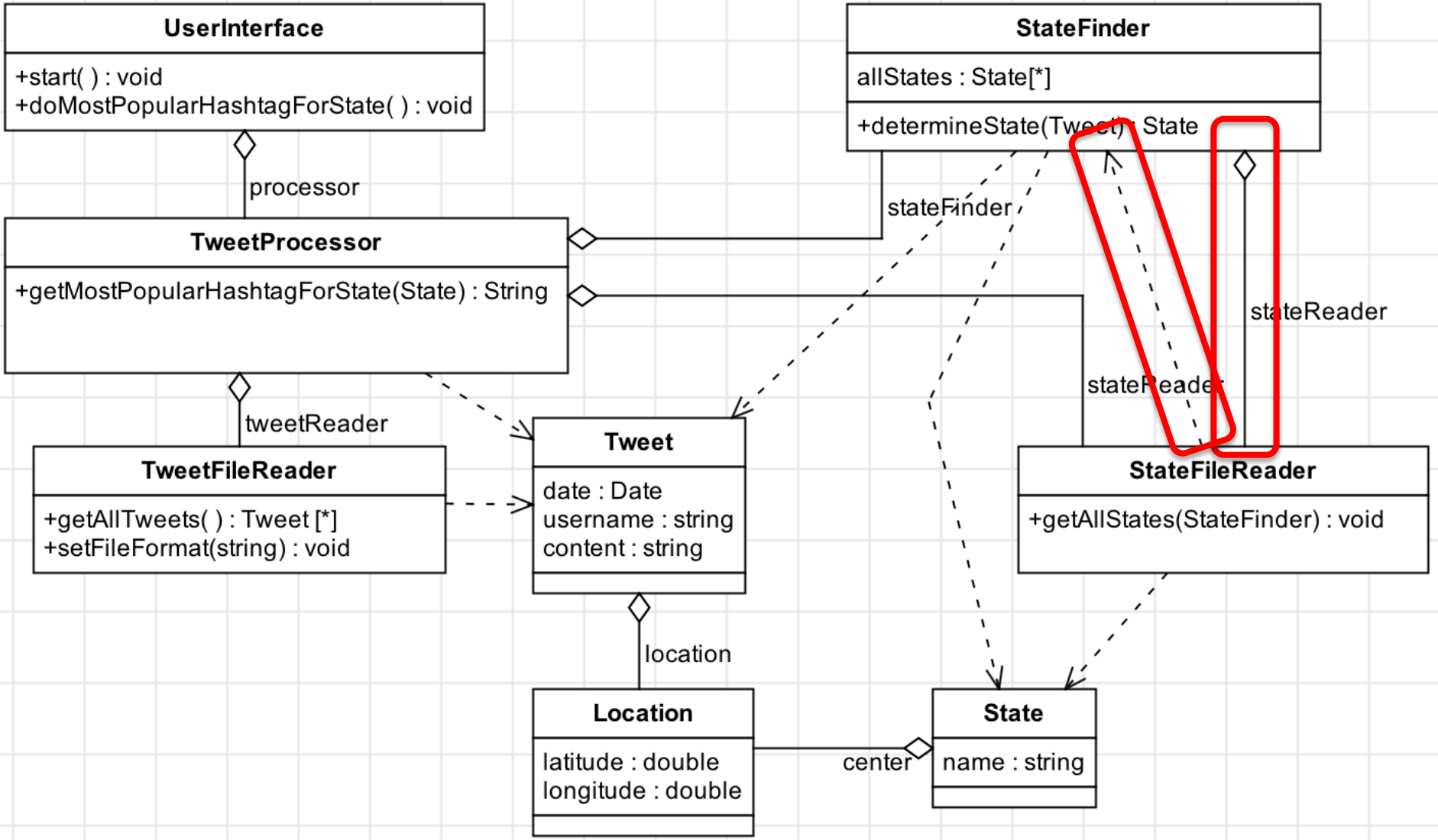
Coupling


UserInterface
+start( ) : void
+doMostPopularHashtagForState( ) : void
processor
TweetProcessor
+getMostPopularHashtagForState(State) : String
tweetReader
TweetFileReader
+getAllTweets( ) : Tweet [*]
+setFileFormat(string) : void
Tweet
date : Date
username : string
content : string
location
Location
latitude : double
longitude : double
StateFinder
allStates : State[*]
+determineState(Tweet) : State
stateFinder
stateReader
stateReader
StateFileReader
+getAllStates(StateFinder) : void
center
State
name : string

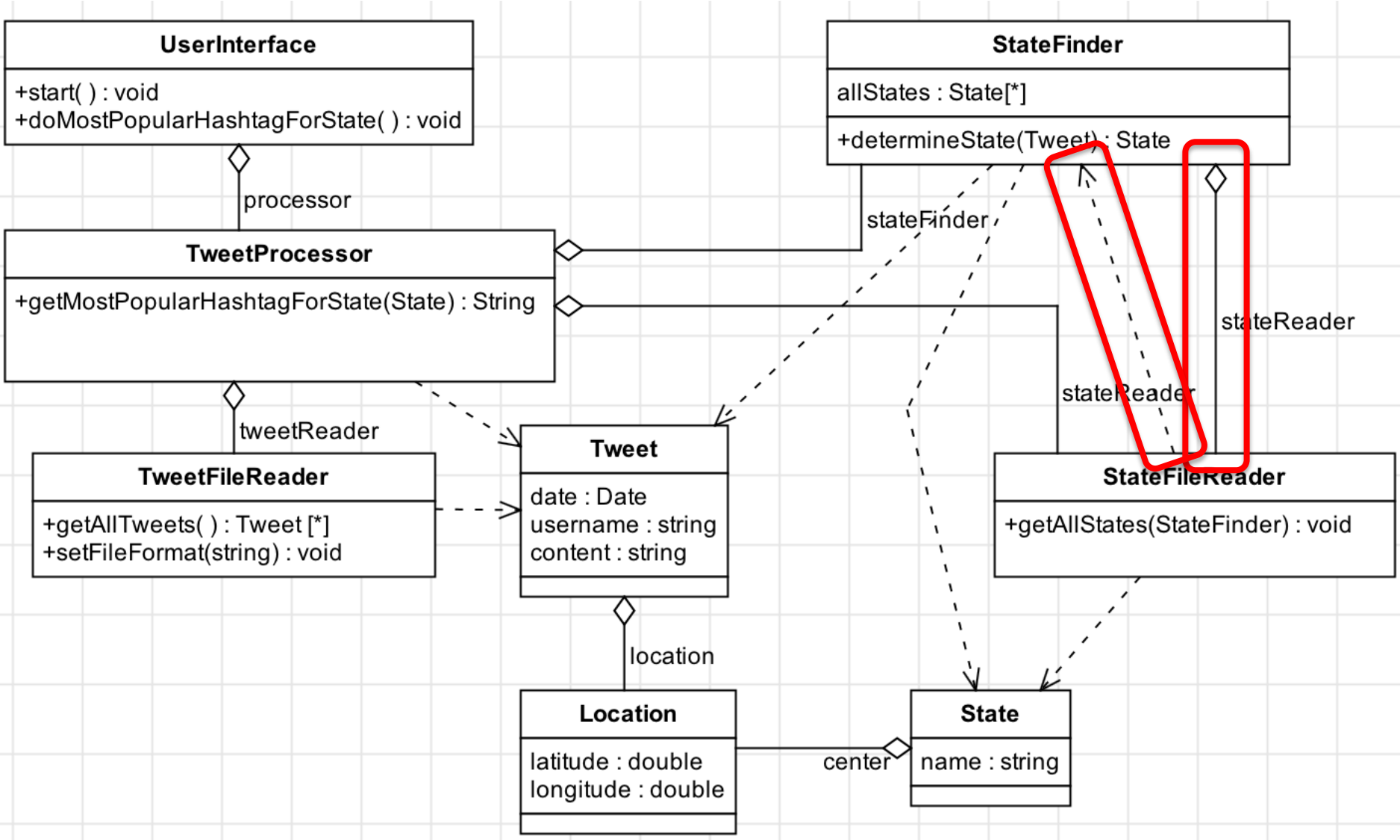
Coupling

- Extent to which one module depends on another

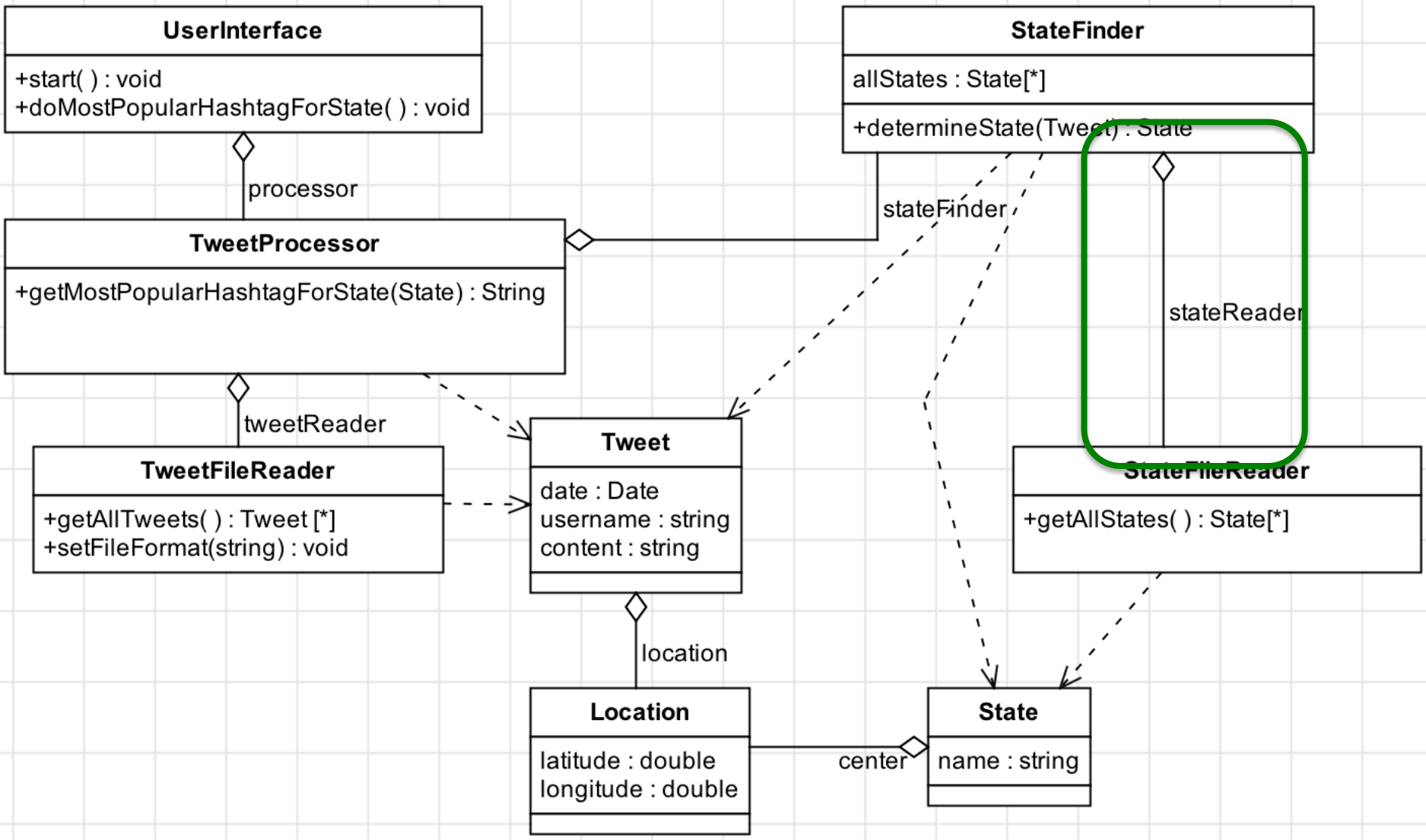
- **Loose coupling**
  - one module depends on another
  - depends only on the data/functionality it requires and nothing more

- **Tight coupling**
  - modules depend on each other
  - modules depend on more data/functionality than is minimally required

Tight Coupling: BAD!



Remove Coupling: GOOD!



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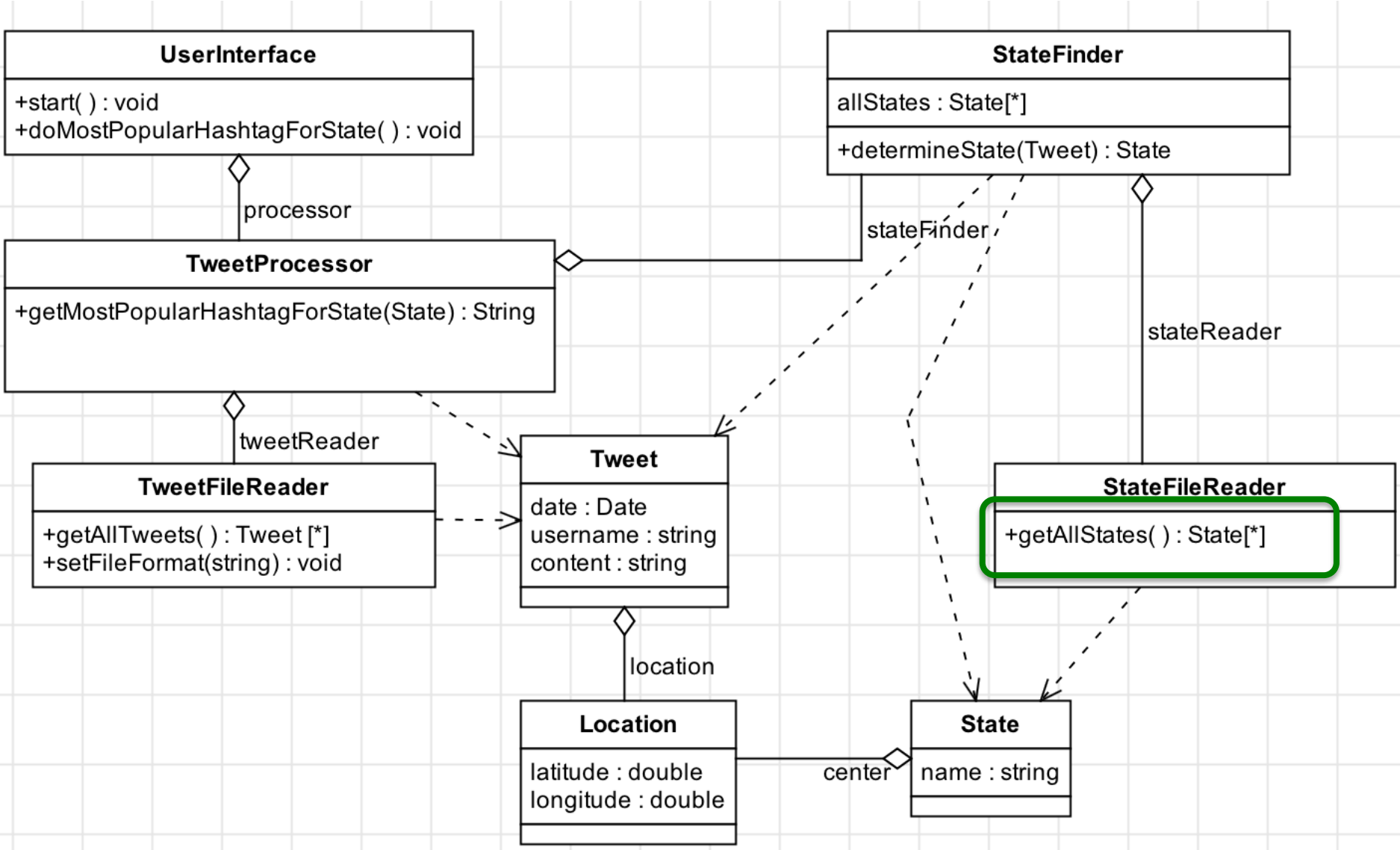

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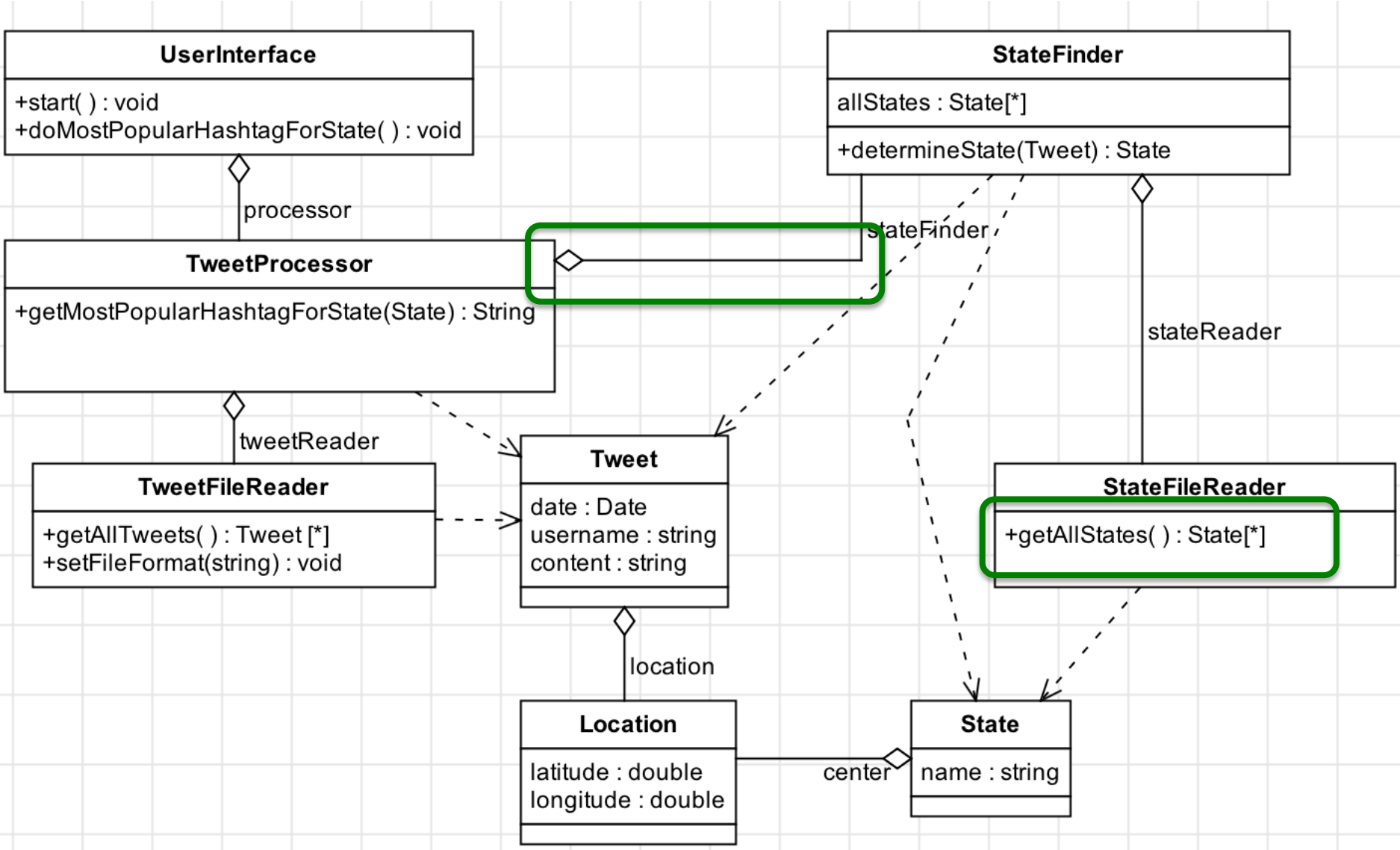

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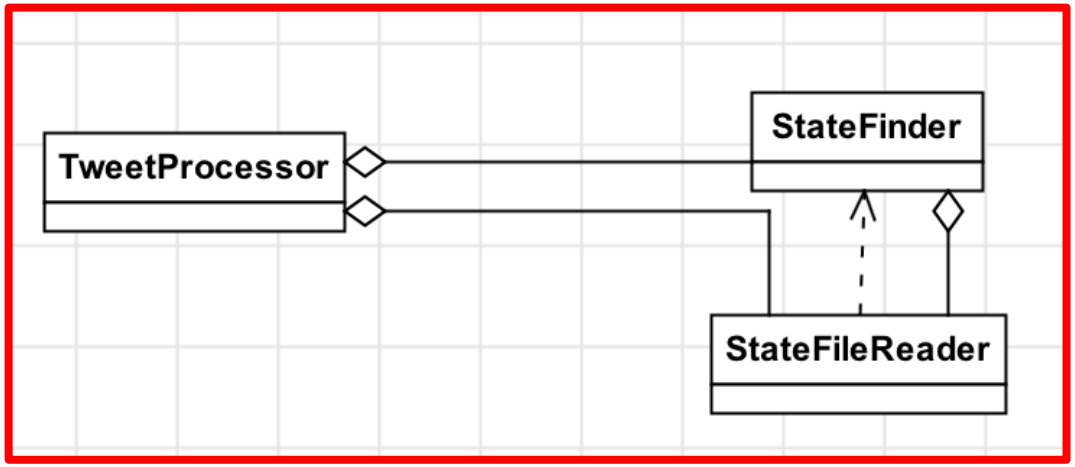

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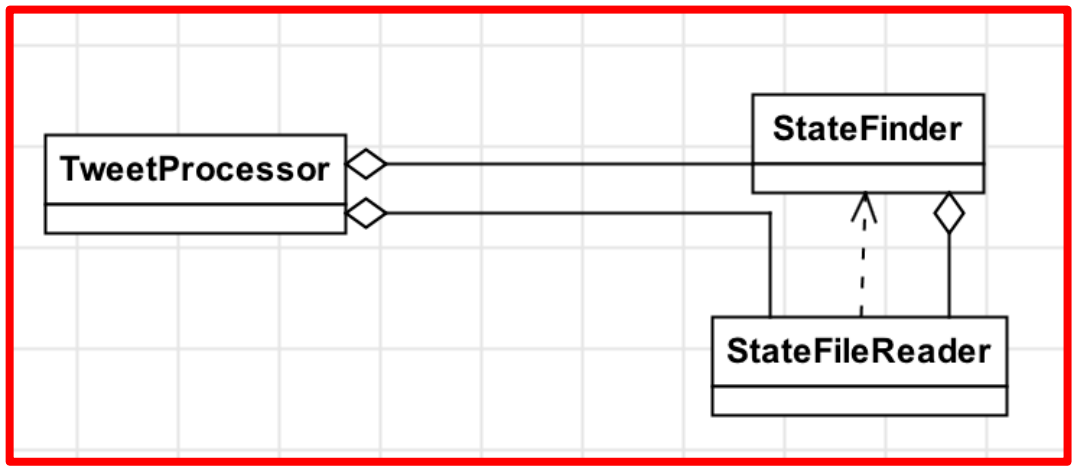
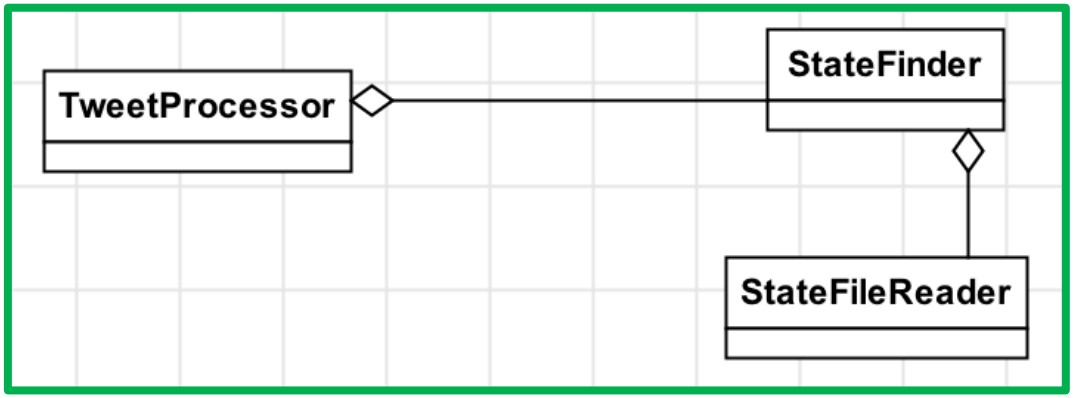


```
public class TweetProcessor {
    protected StateFinder stateFinder;

    public TweetProcessor() {
        stateFinder = new StateFinder();
    }
    . . .
}
```



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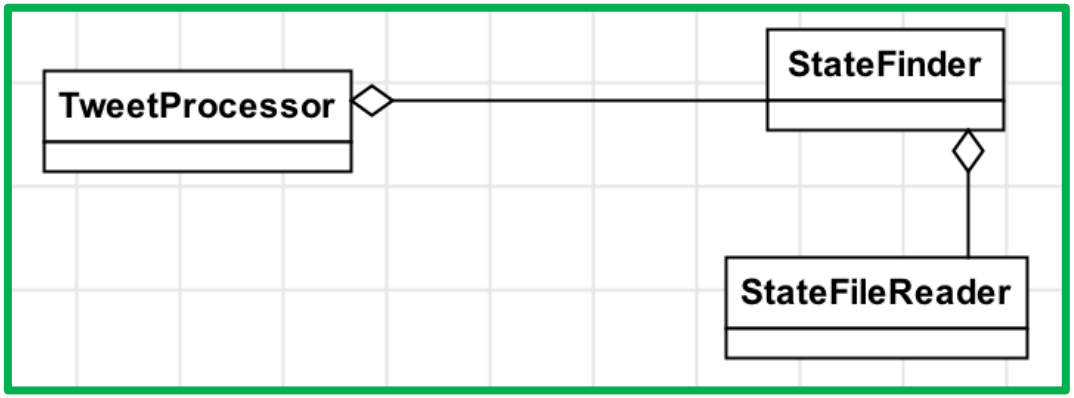

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```
public class StateFinder {

    protected State[] allStates;
    protected StateFileReader stateReader;

    public StateFinder() {
        stateReader = new StateFileReader();
        allStates = stateReader.getAllStates();
    }

    . . .
}
```

```
public class TweetProcessor {
    protected StateFinder stateFinder;

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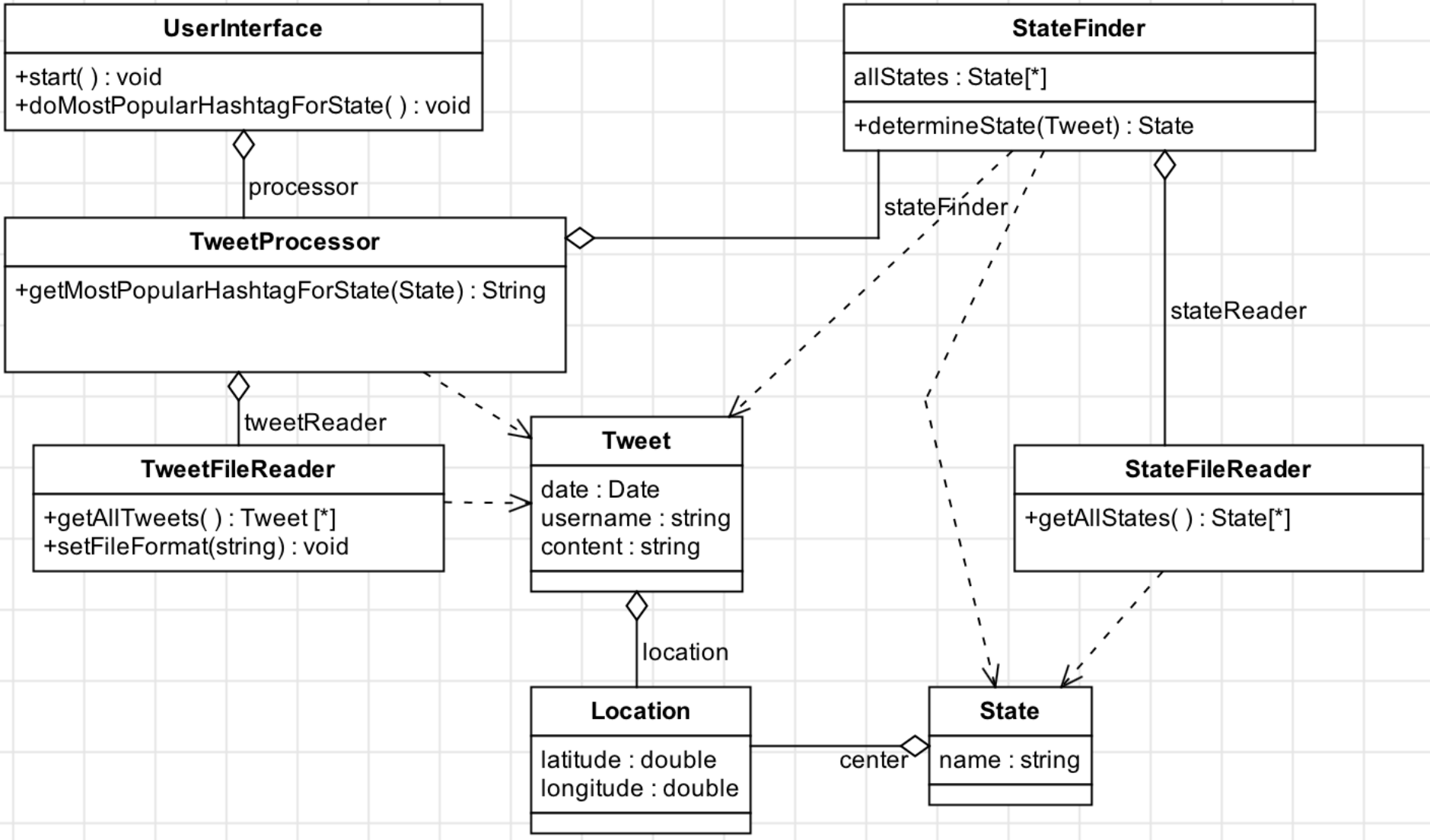
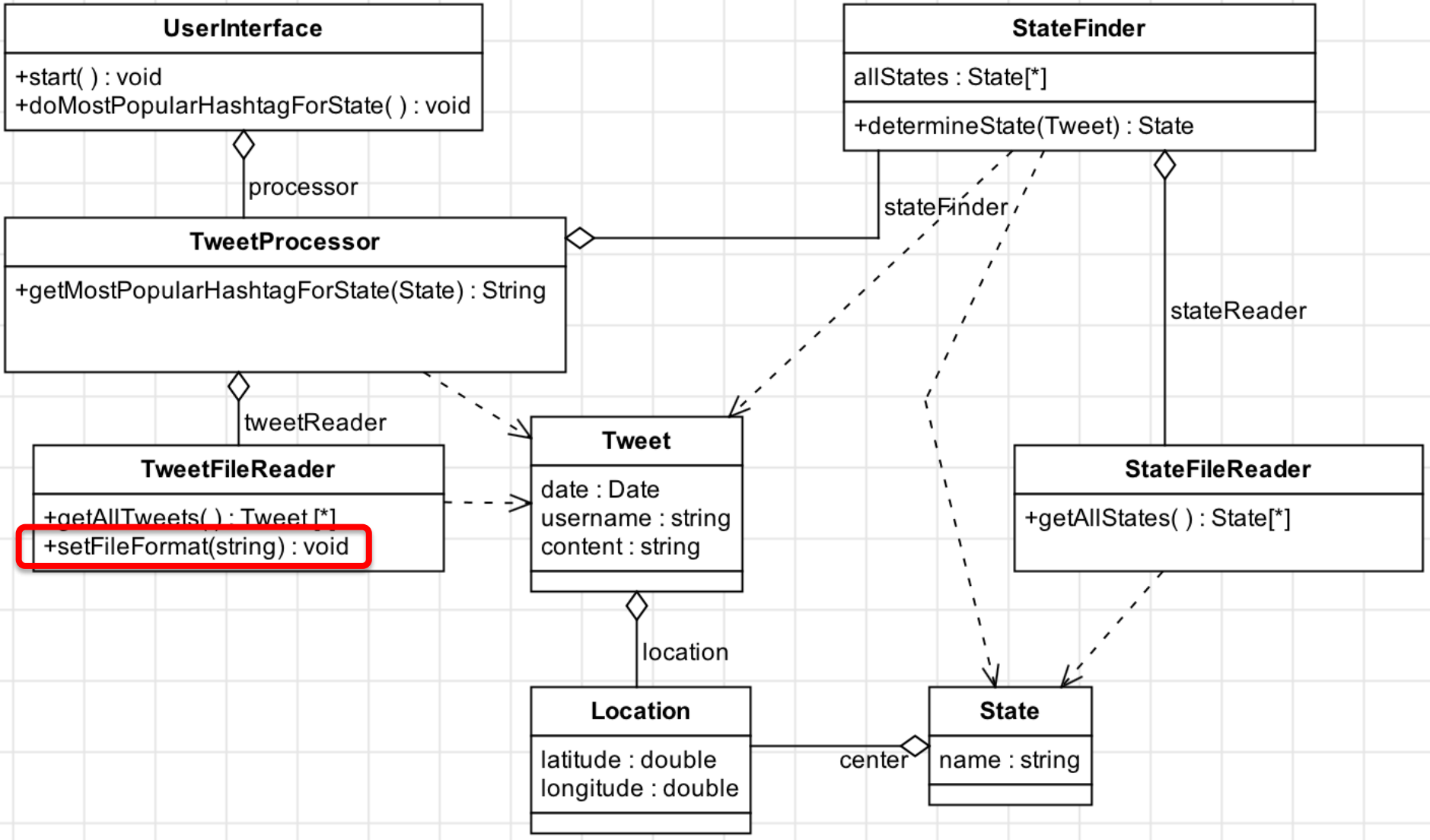
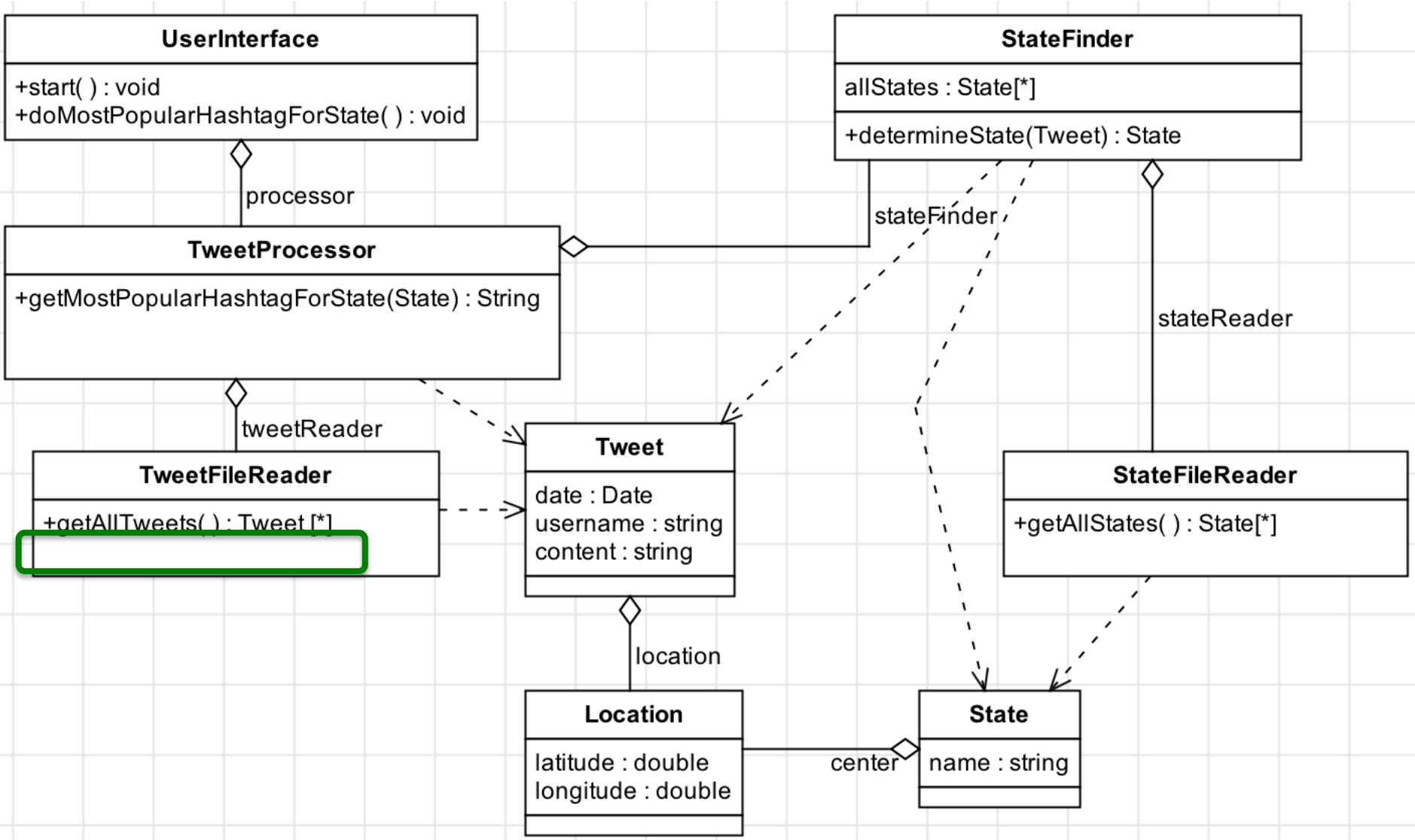
Modules should be self-contained



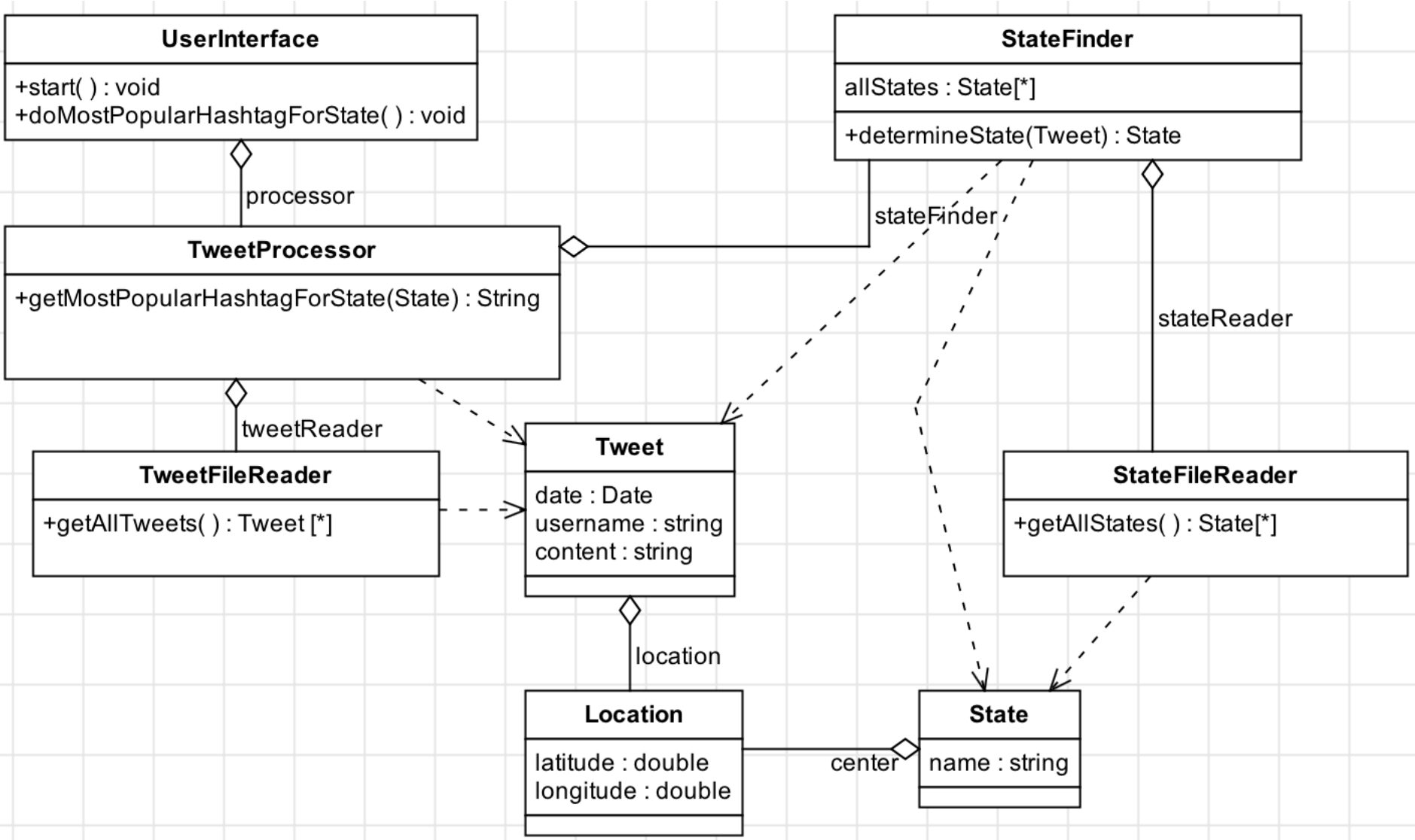
Modules should be self-contained



Modules should be self-contained



Simplify dependencies



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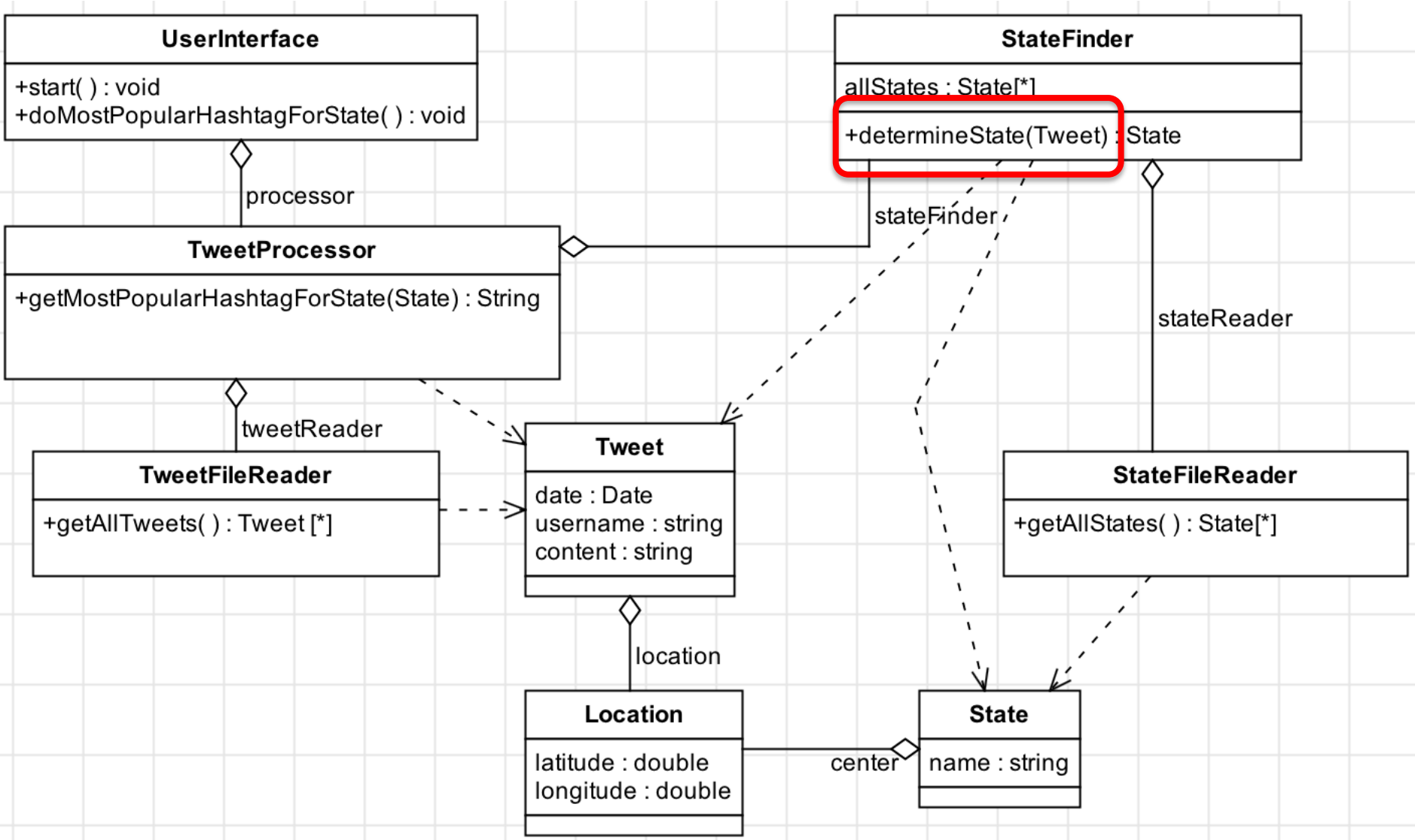

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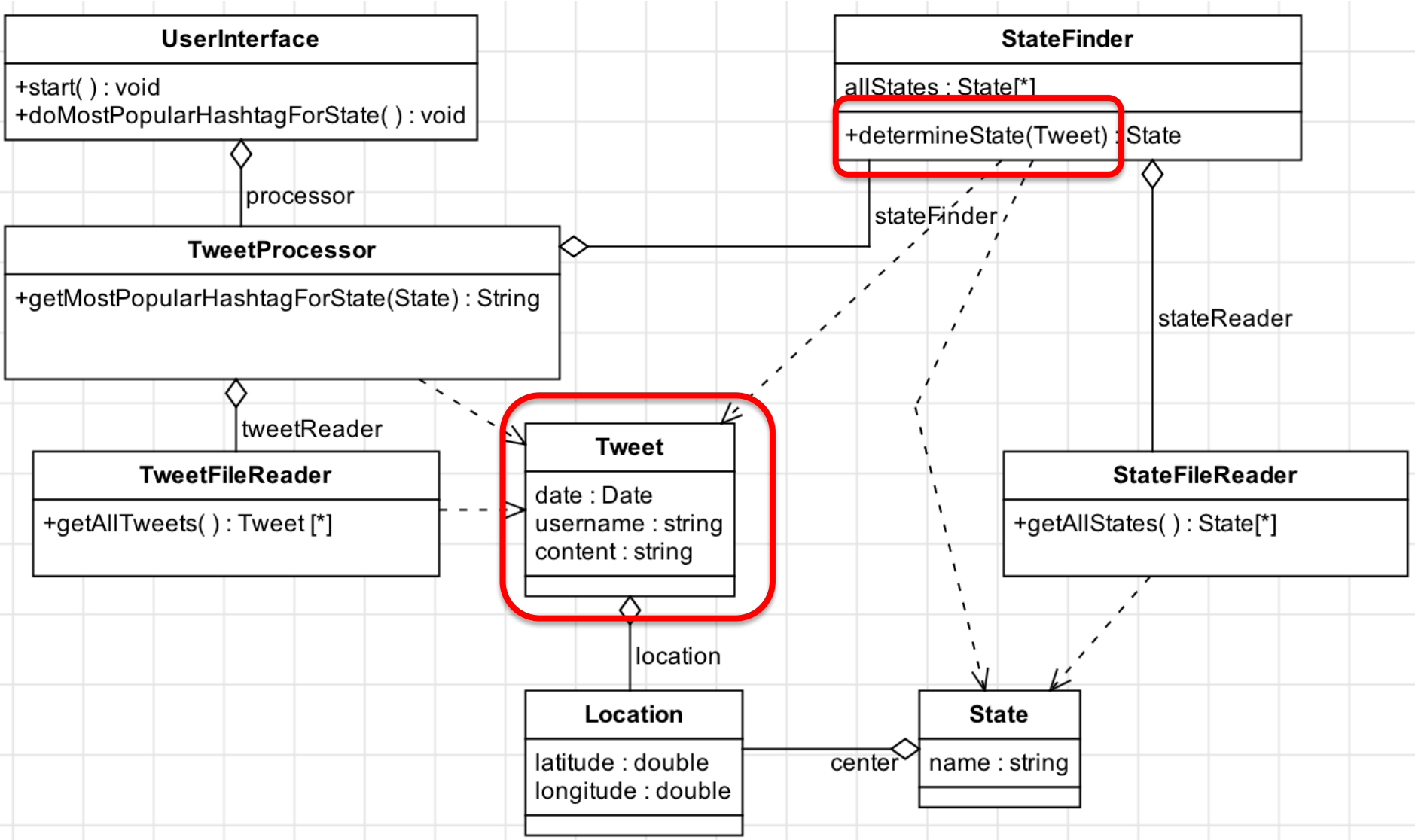

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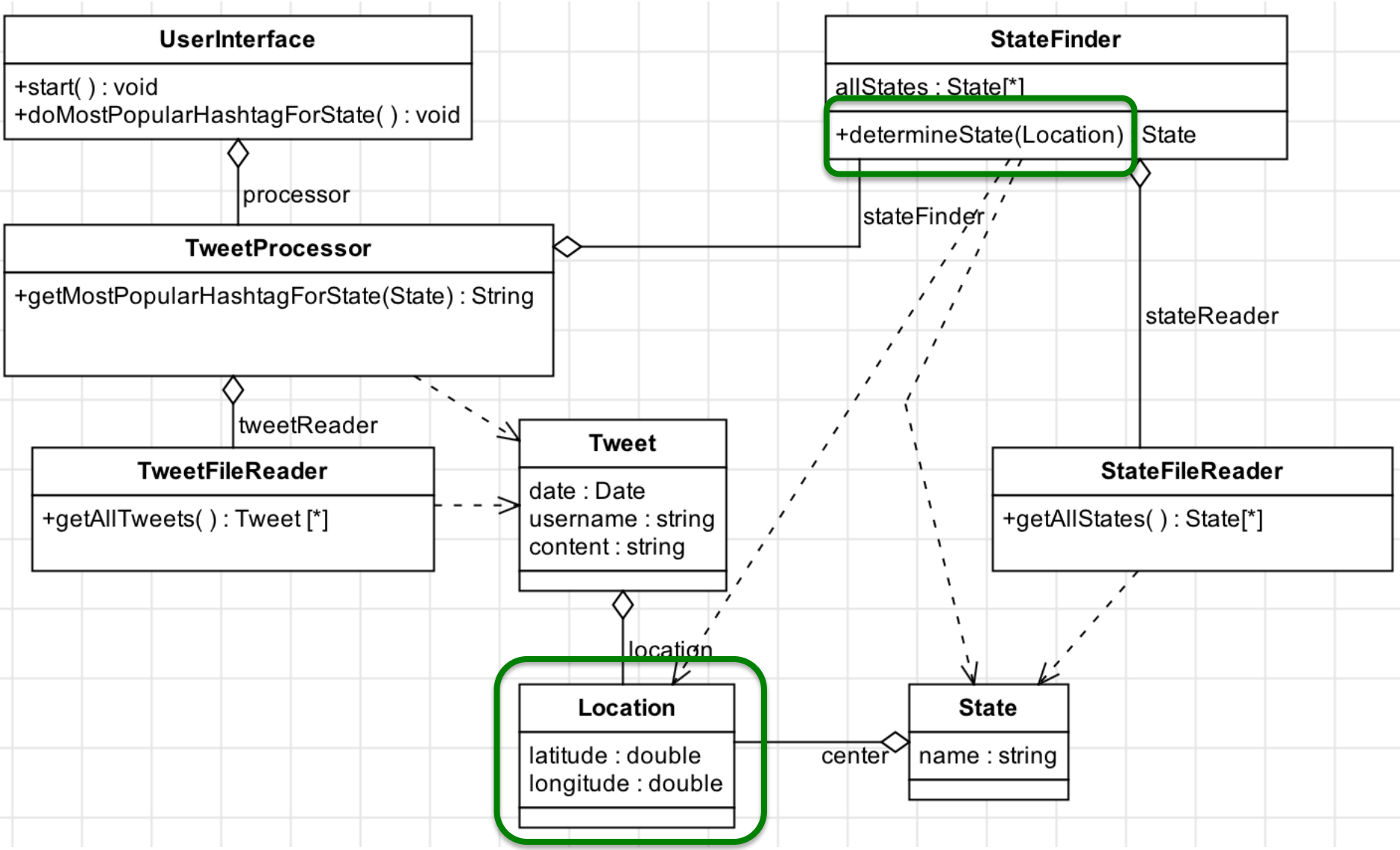

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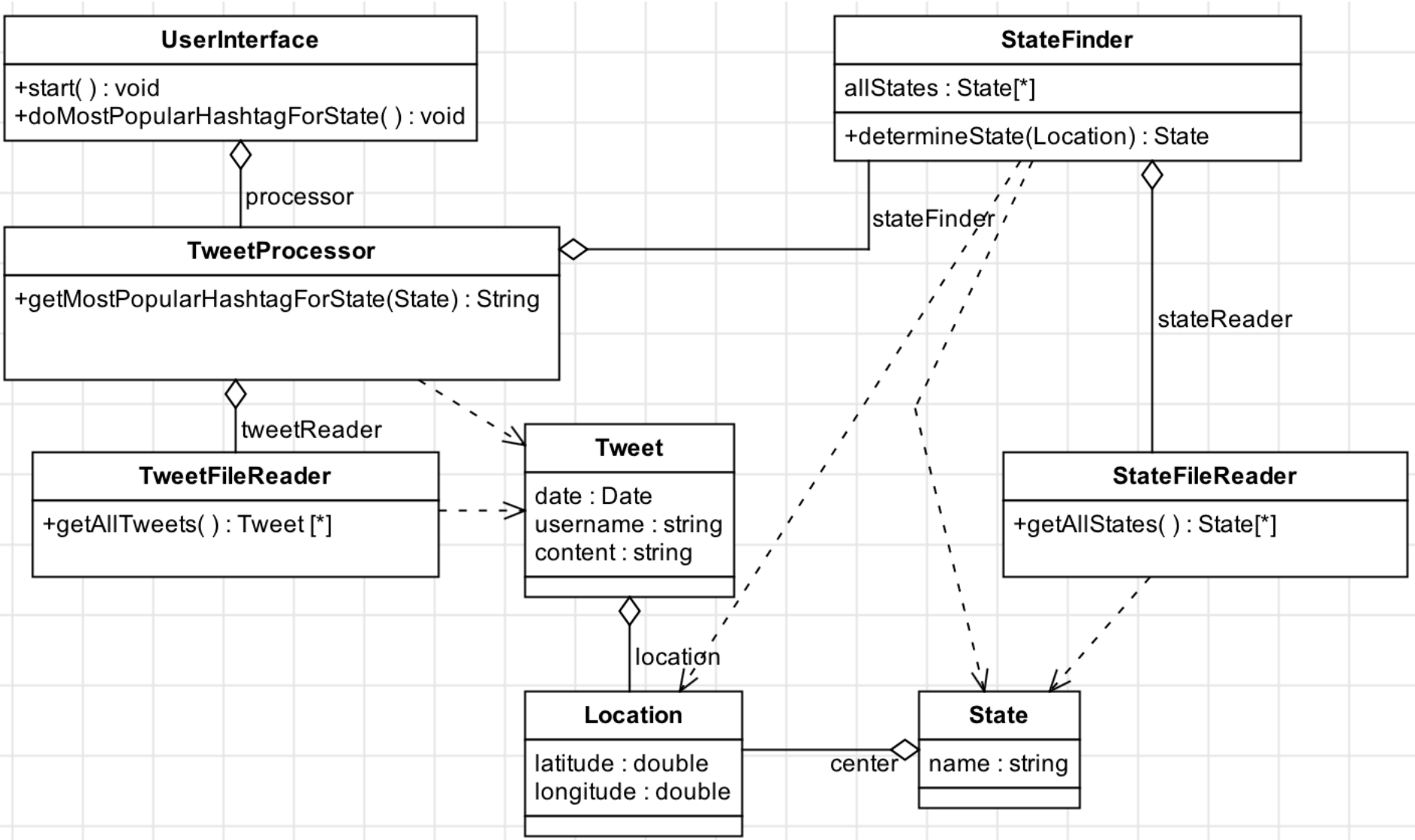

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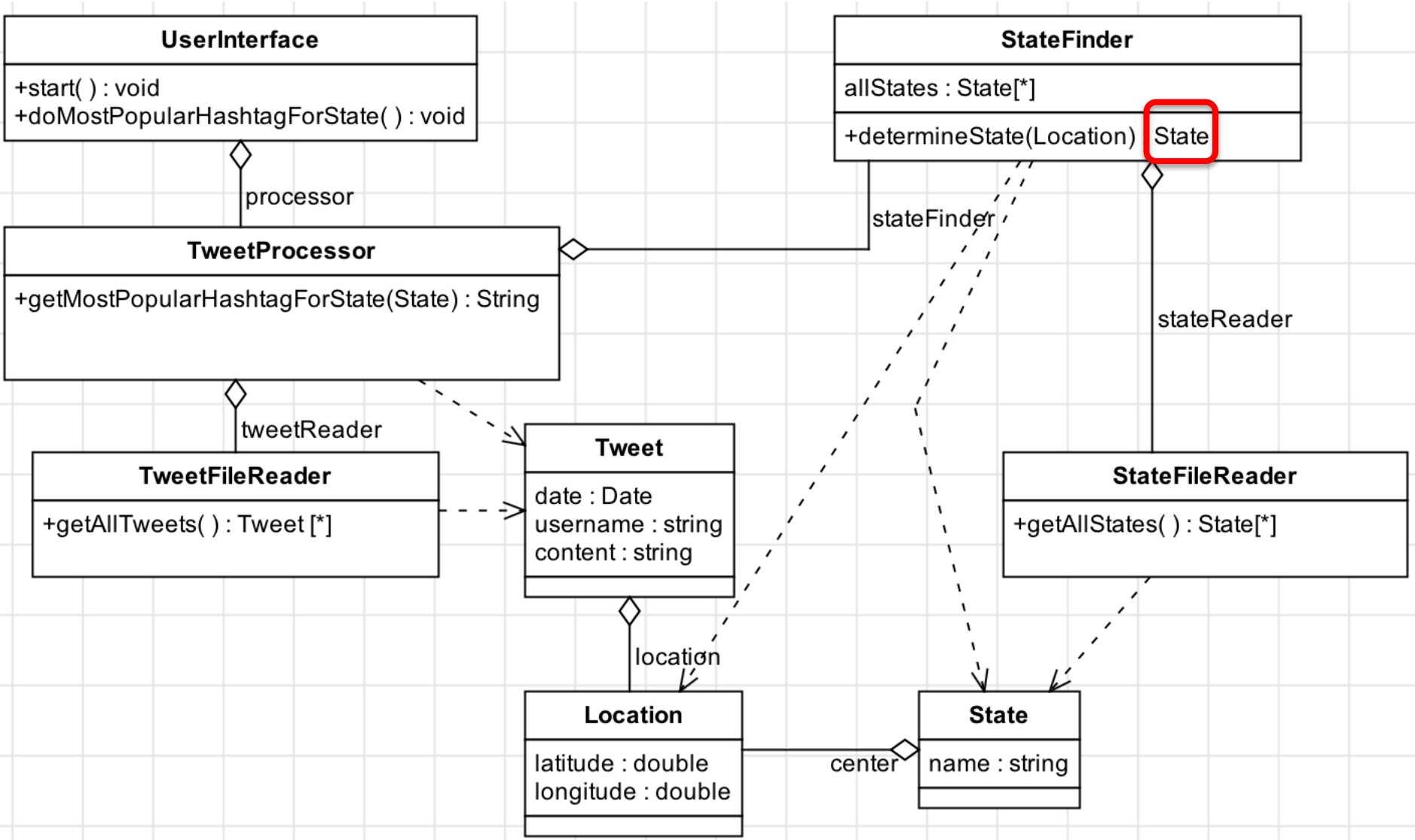

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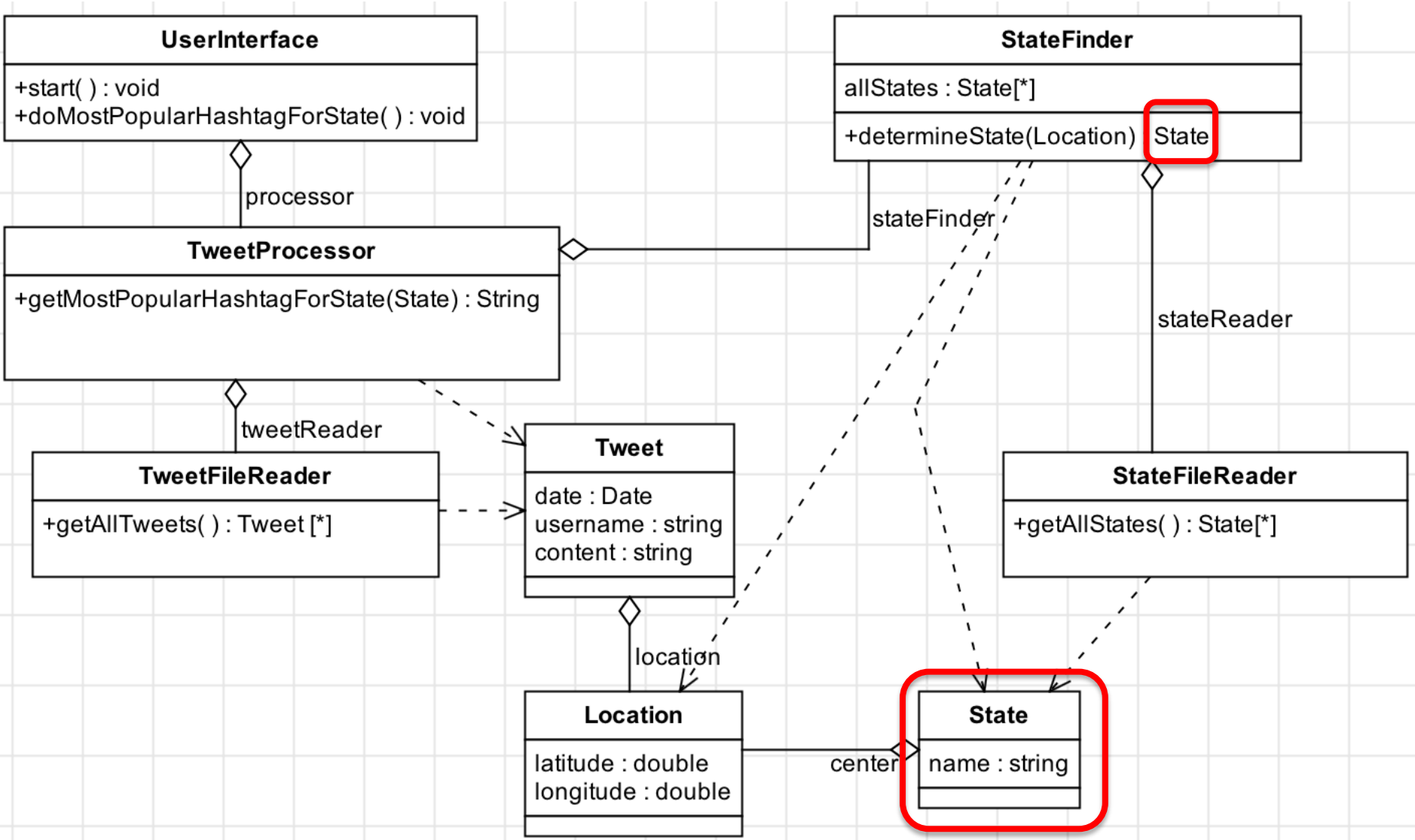

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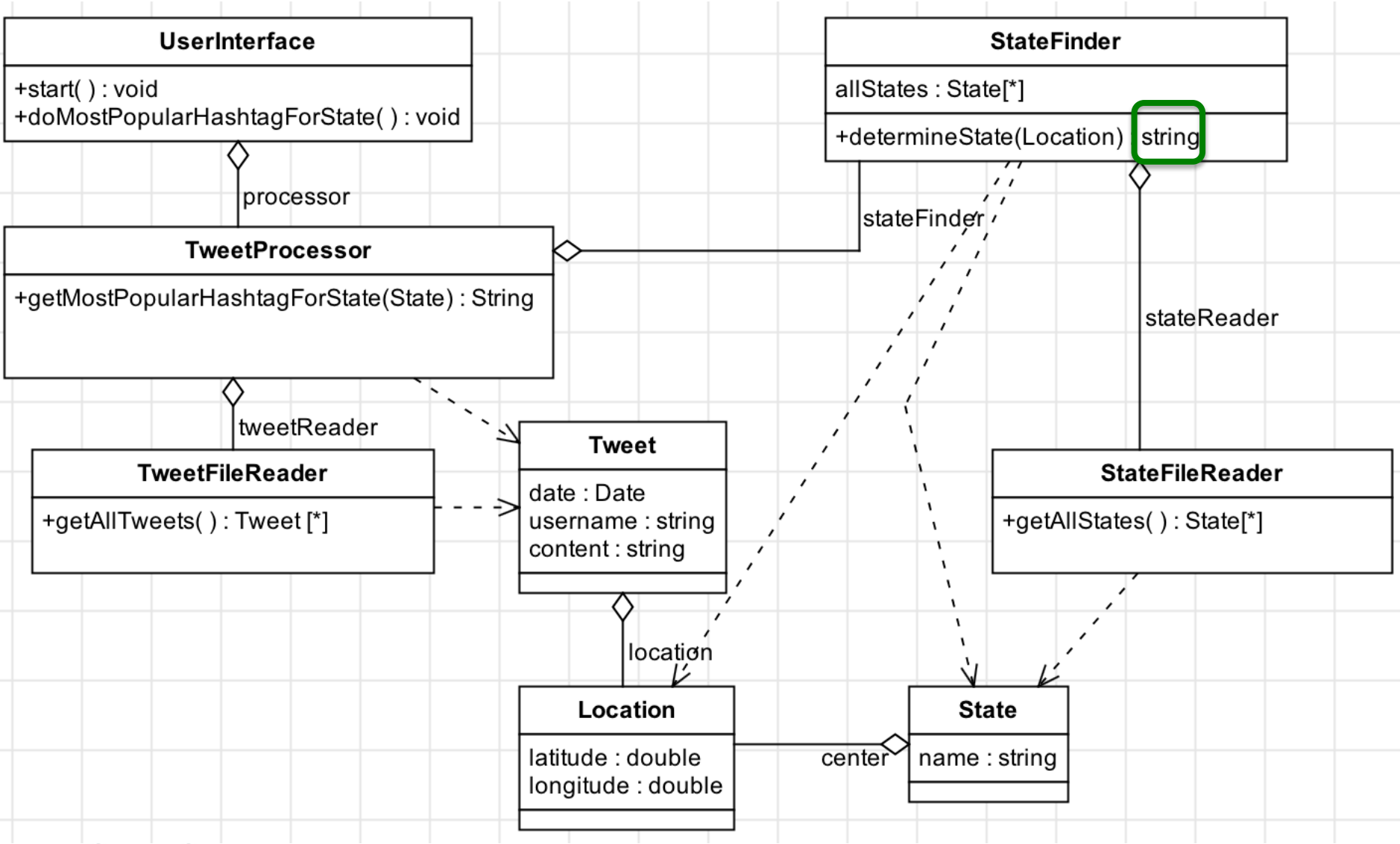

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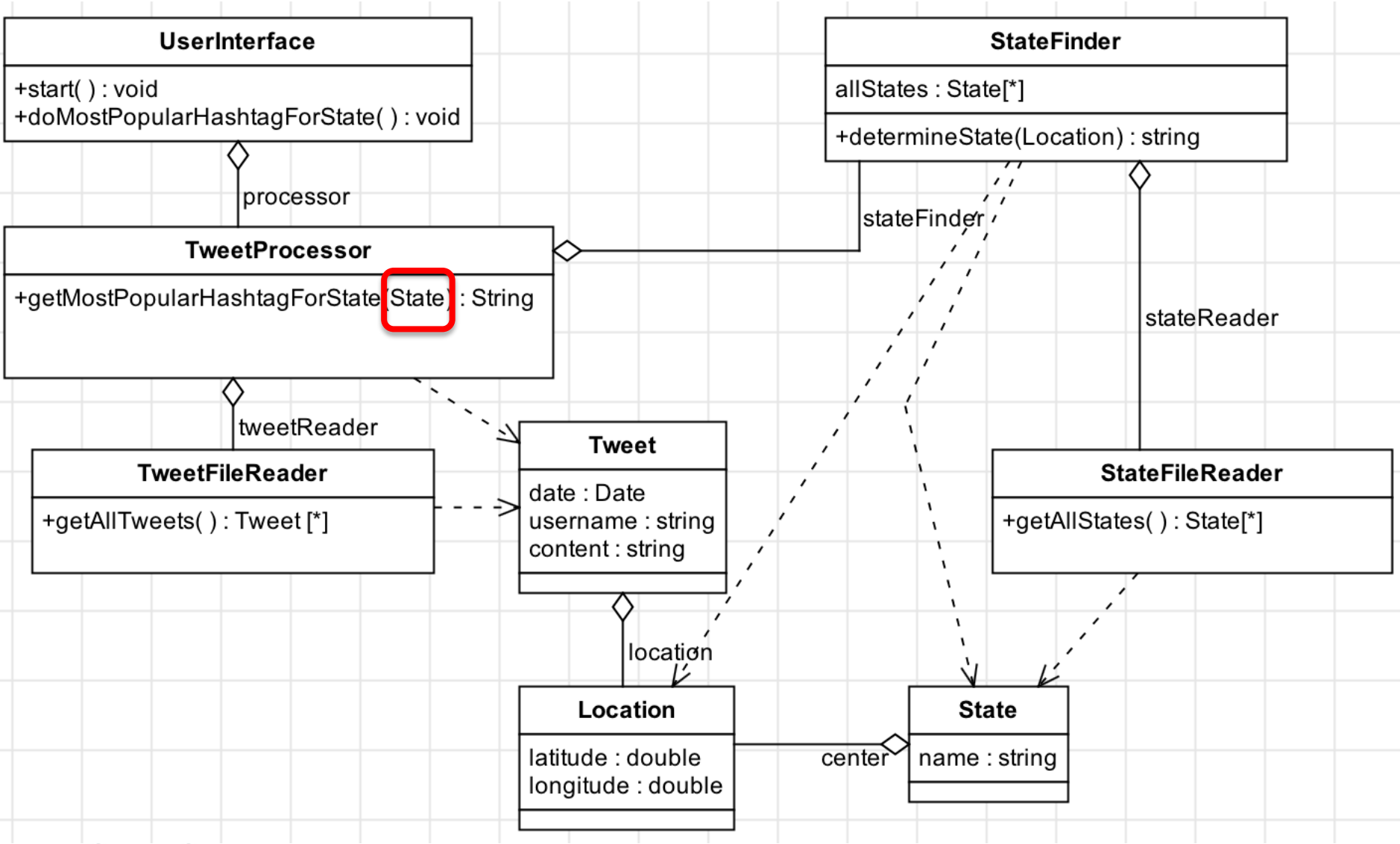

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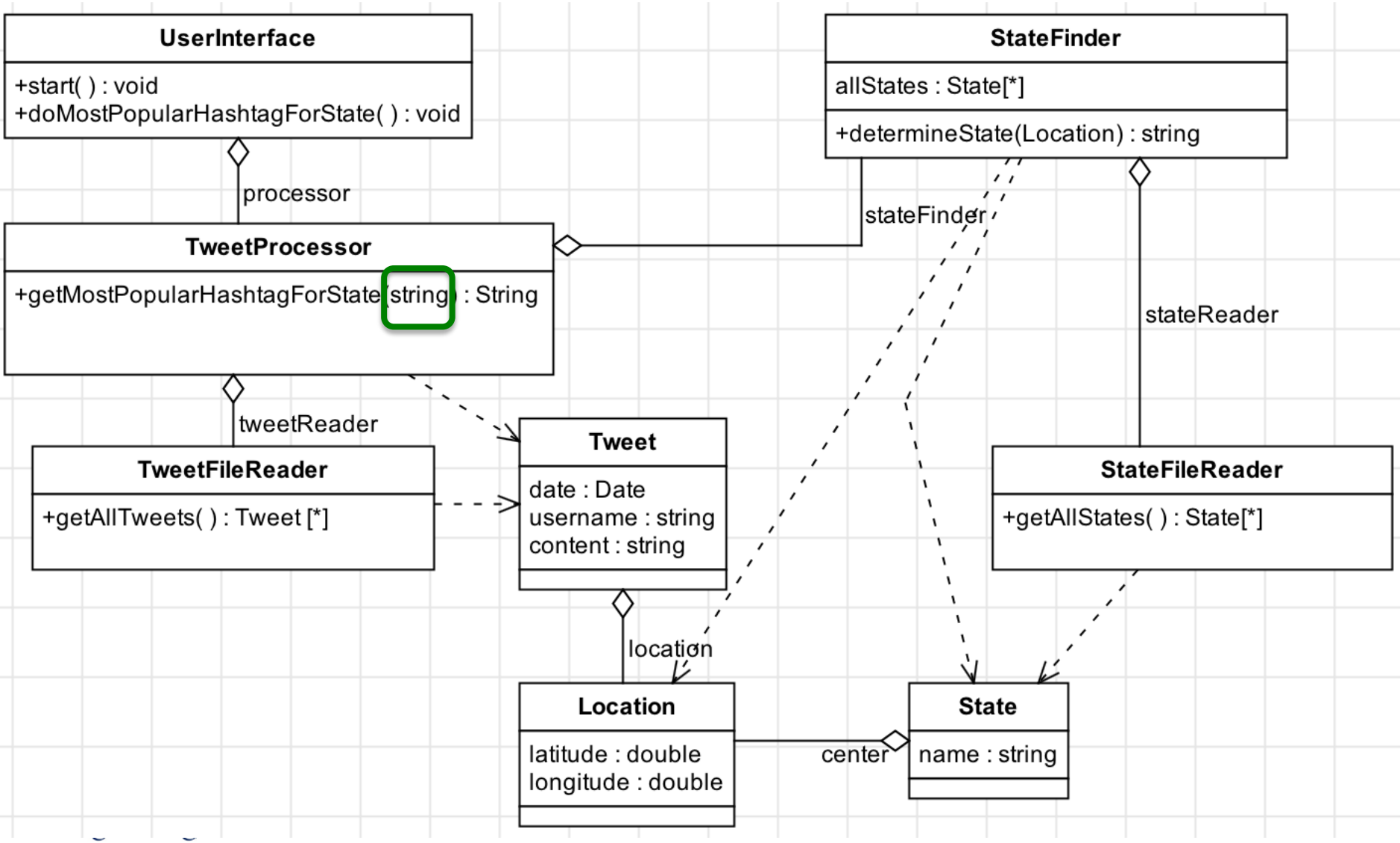
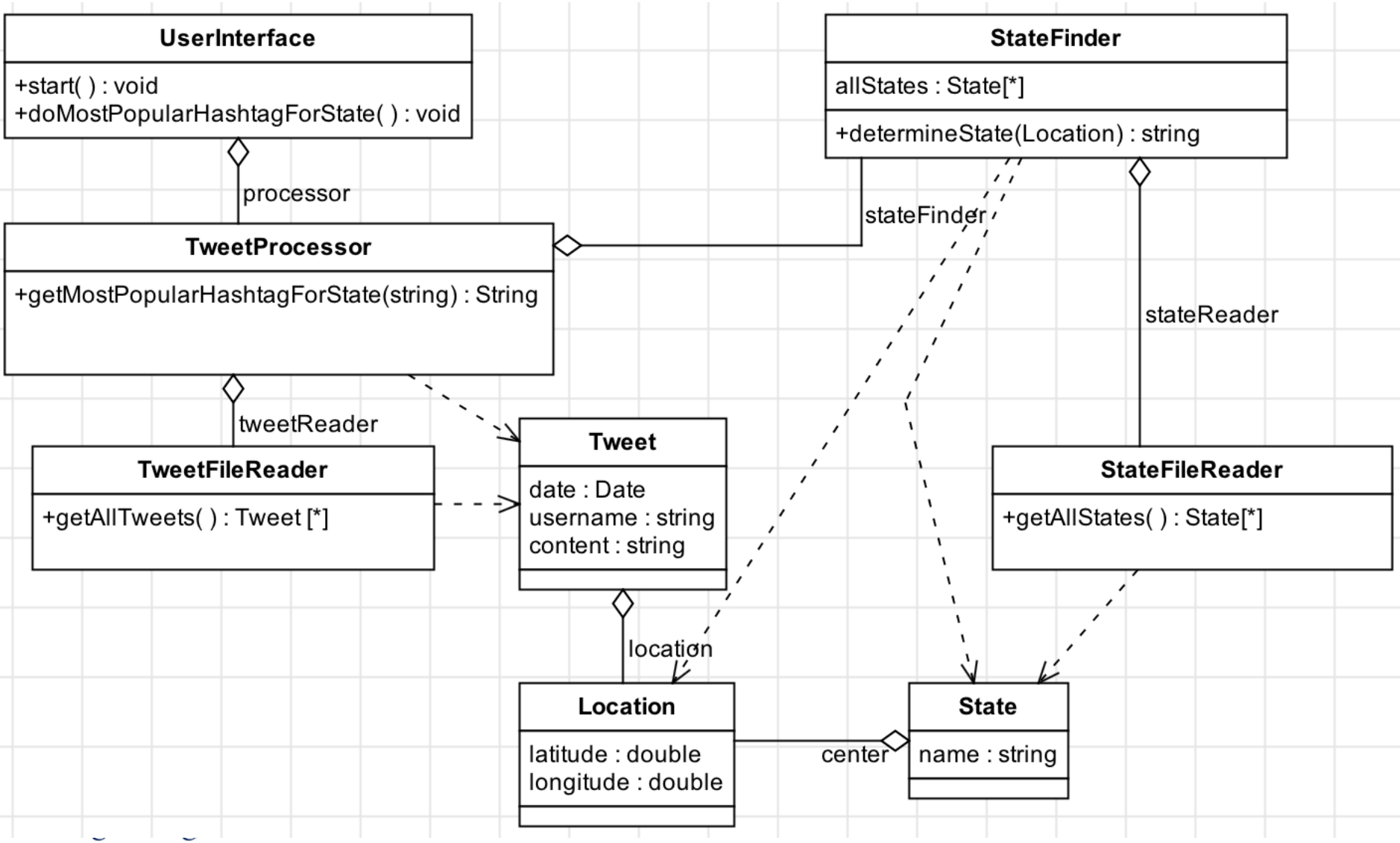


A functionally independent design



Recap: Functional Independence

- A module should be able to do its work with minimal dependence on other modules

- Avoid tight coupling (cyclic dependencies)
- Let modules be self-contained
- Simplify dependencies

SD2x3.9

Abstraction

Chris

Software Design Concepts

Modularity

Functional Independence

Abstraction

Software Design Concepts

Modularity

Functional Independence

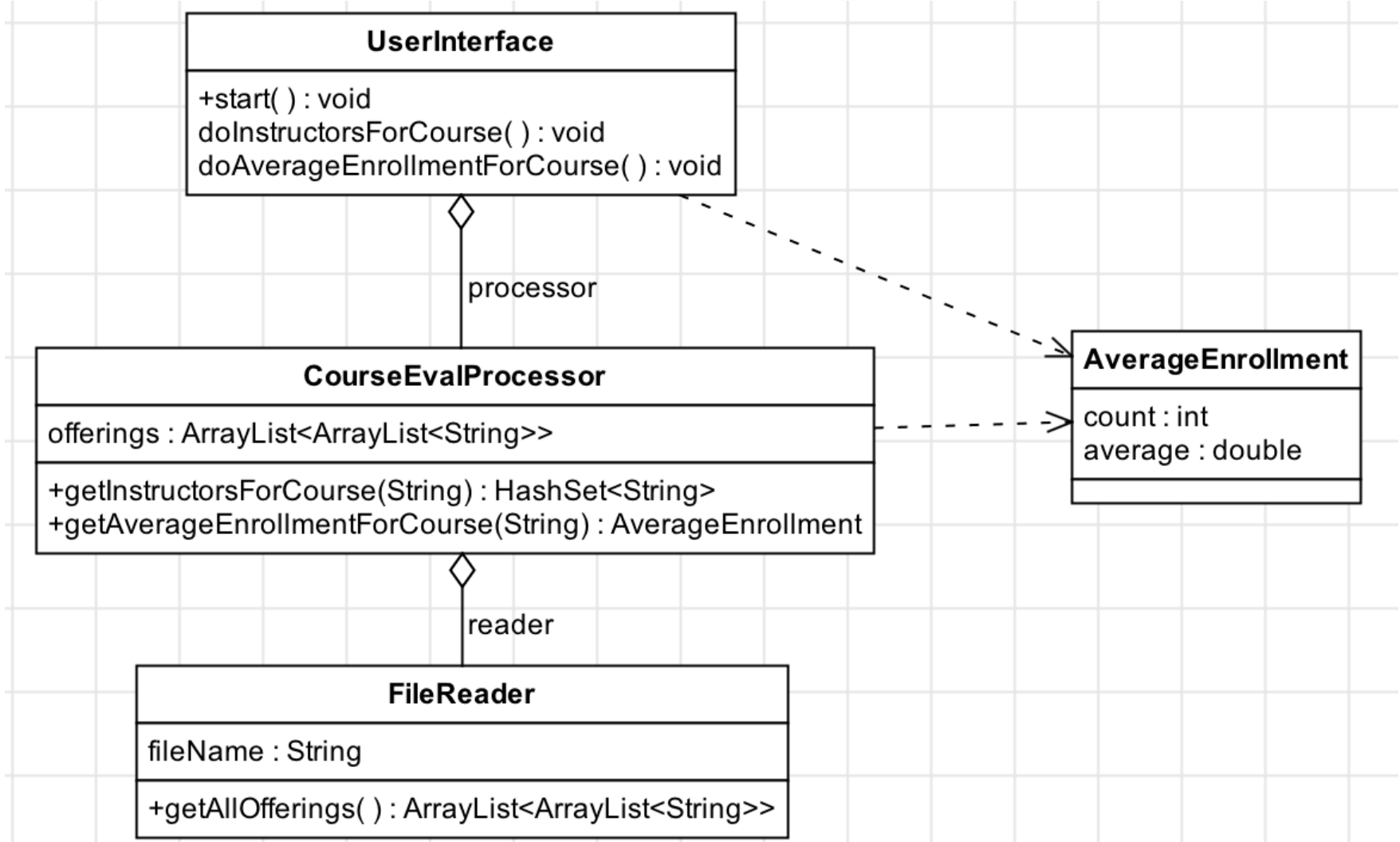
Abstraction

Motivating Example

- Design a Java program that reads a file containing info about courses, instructors, and enrollment

- And then allows the user to choose to see either:
  - the instructor(s) for a given course
  - the average enrollment for the course

A Modular Design



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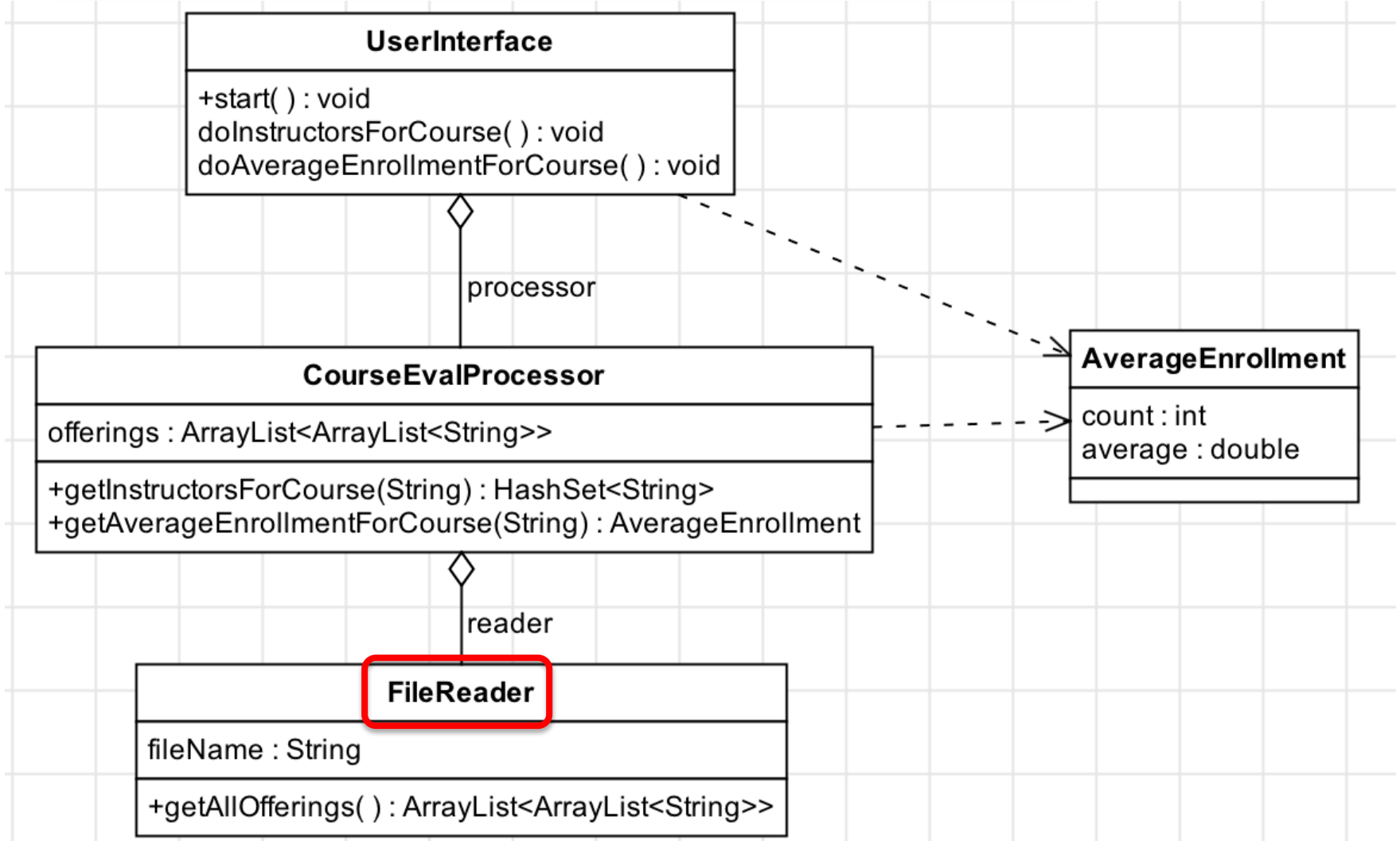

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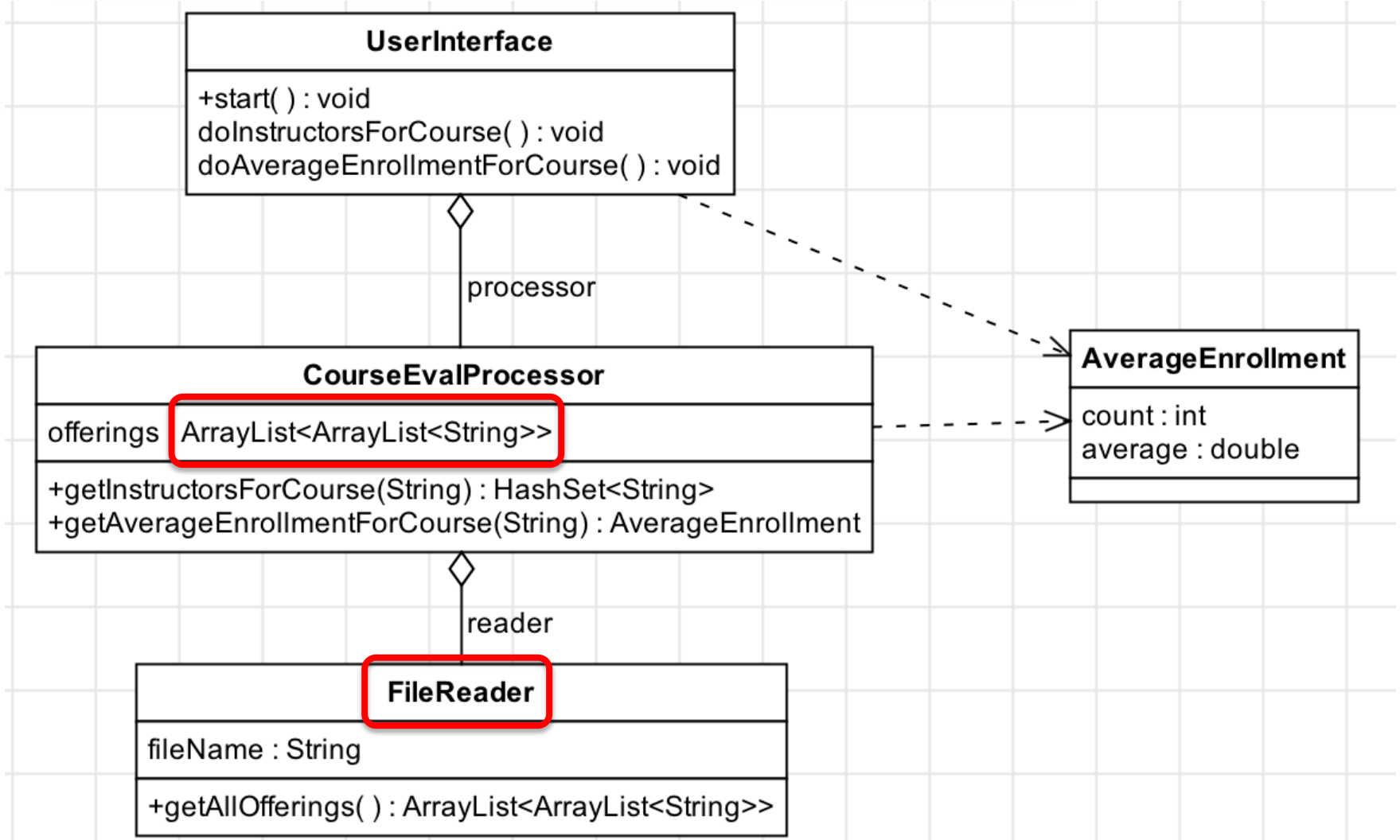

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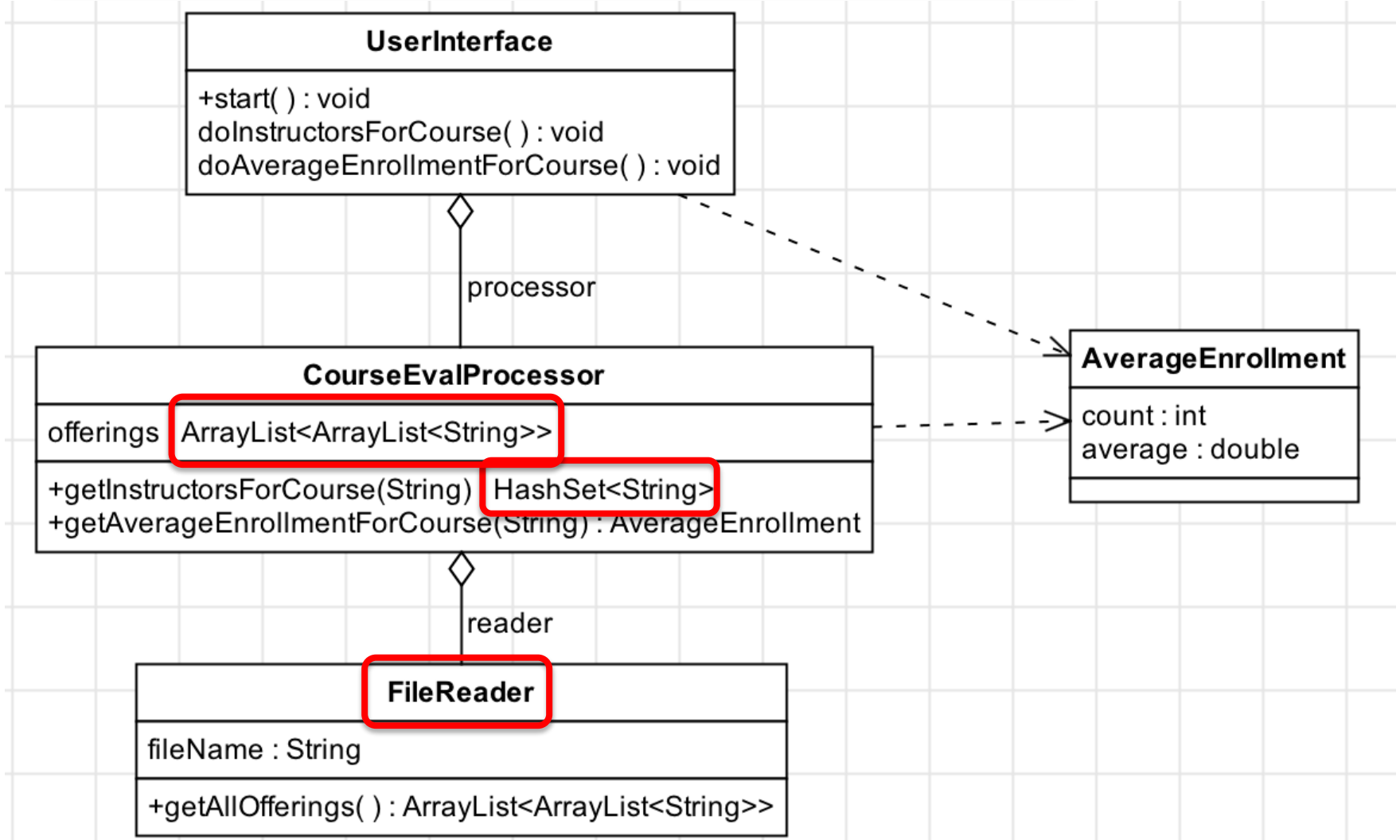


Abstraction

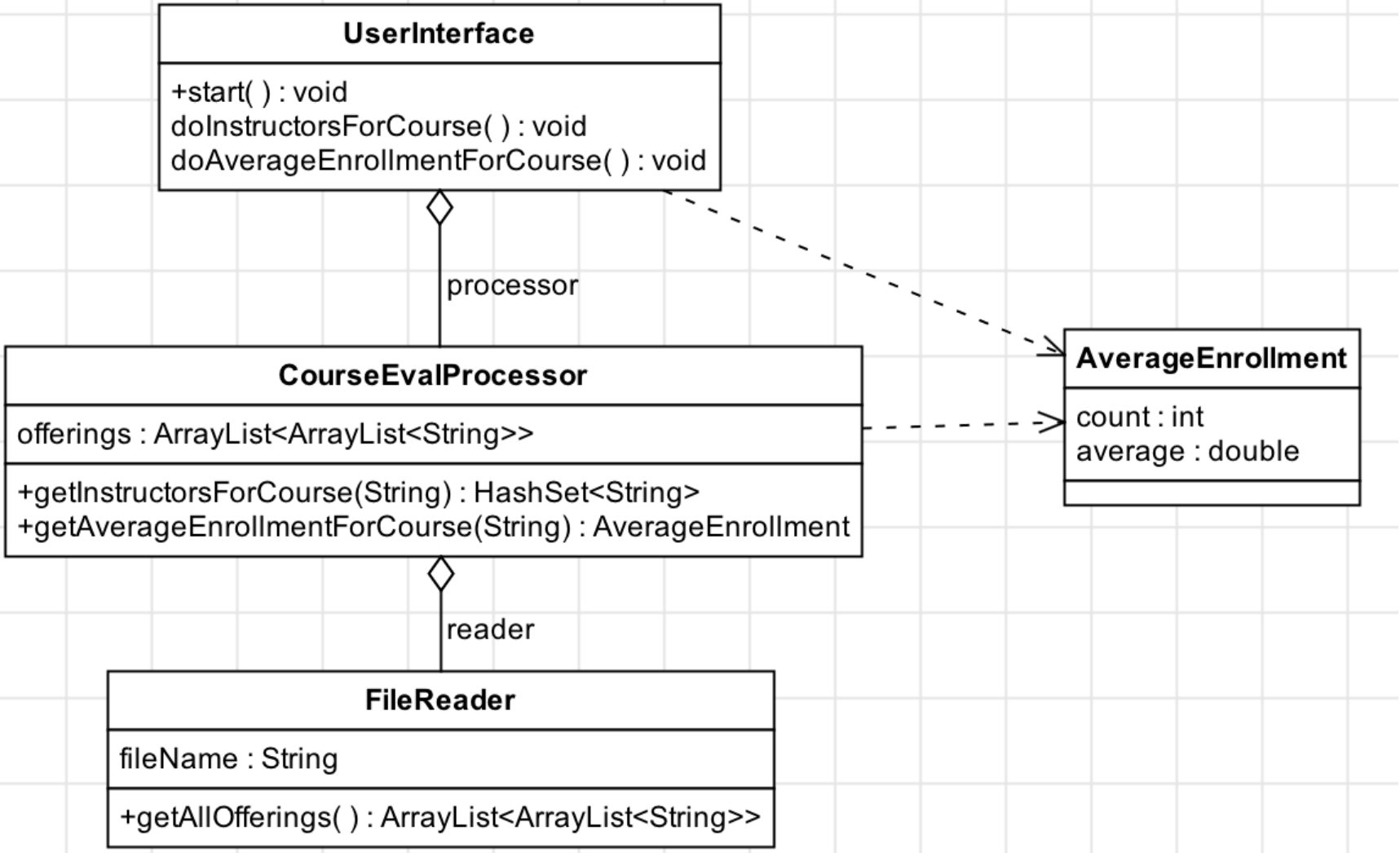
- A module can use other modules with minimal knowledge of the details of their implementation
- Should only care *what* they do (services they provide) and not *how* they do it
- “Program to an interface, not an implementation”

Why abstraction?

- **Stability:** can change a module's implementation details with no changes required to modules that depend on it

- **"Reusability":** a module can be reused if it doesn't need to know the details of the things on which it depends

How can we improve abstraction?



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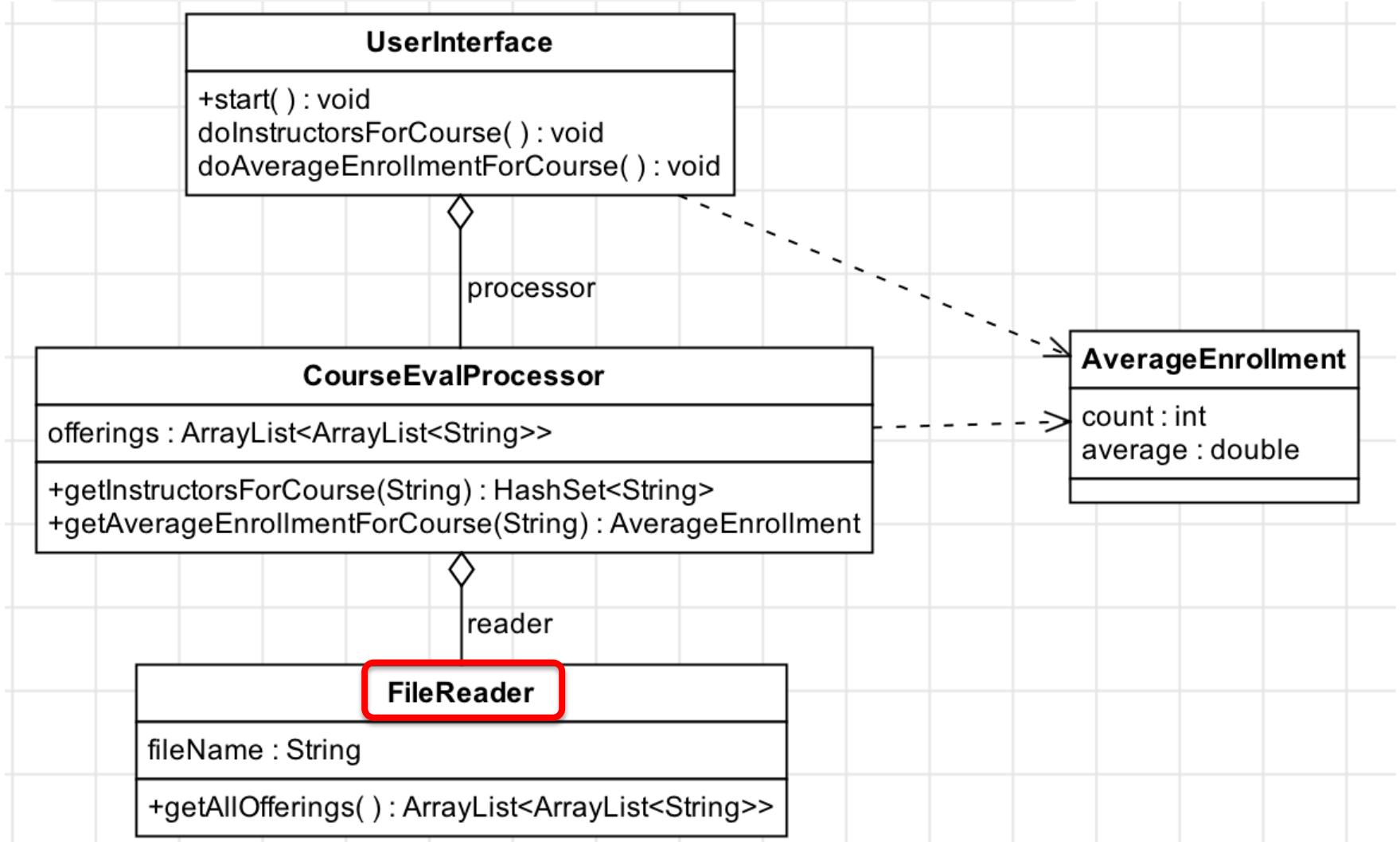
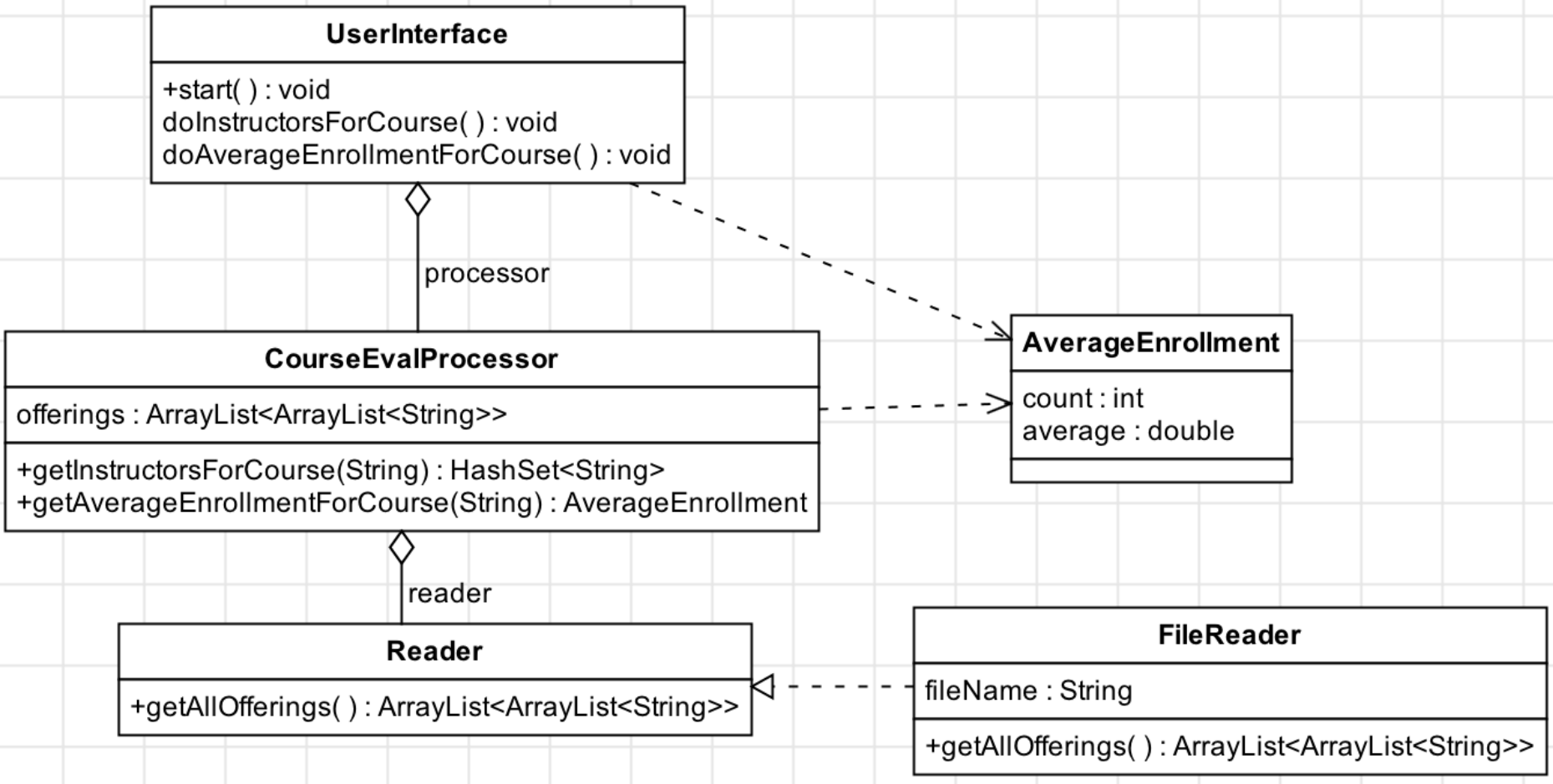
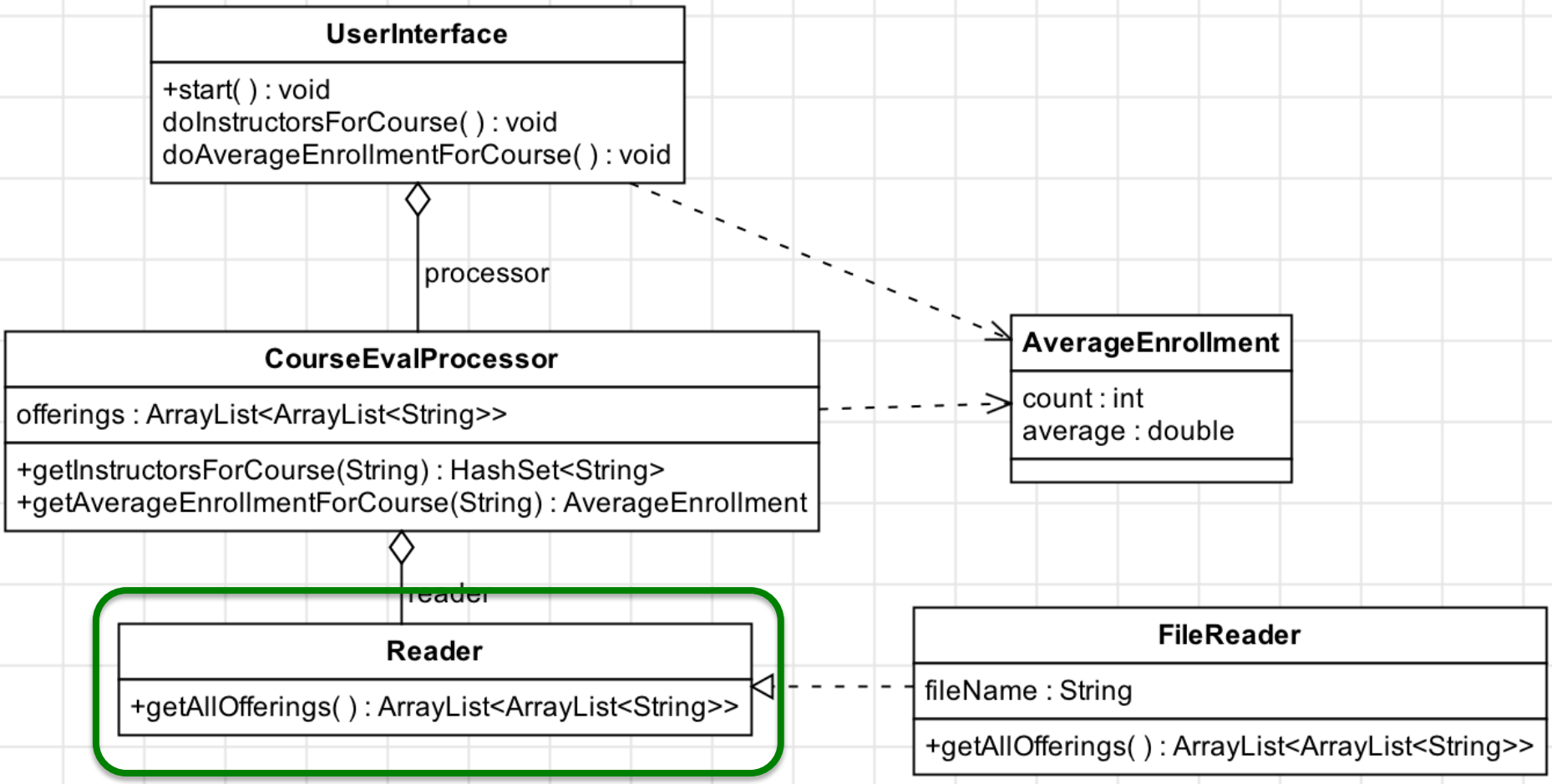


A more abstract design



A more abstract design



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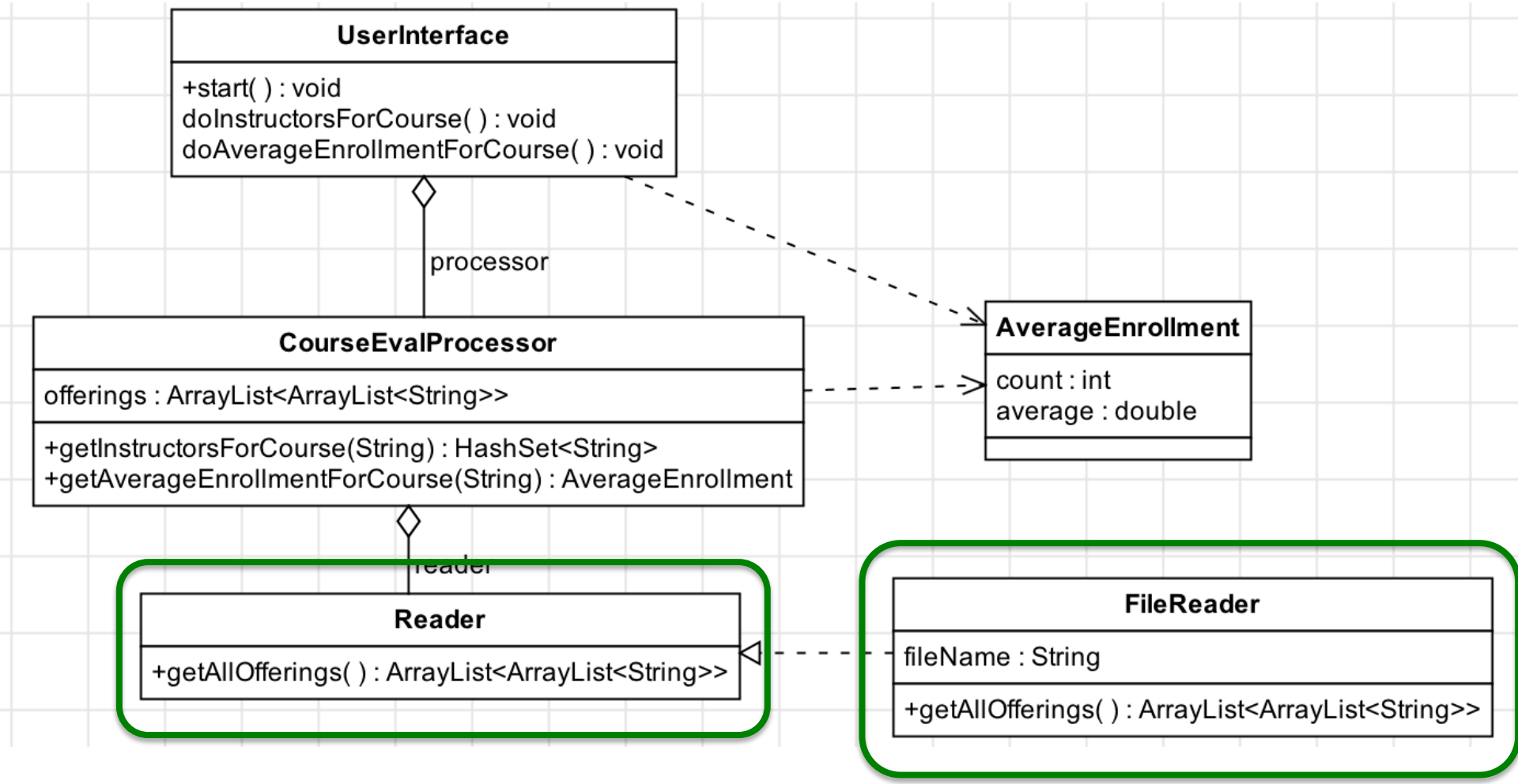
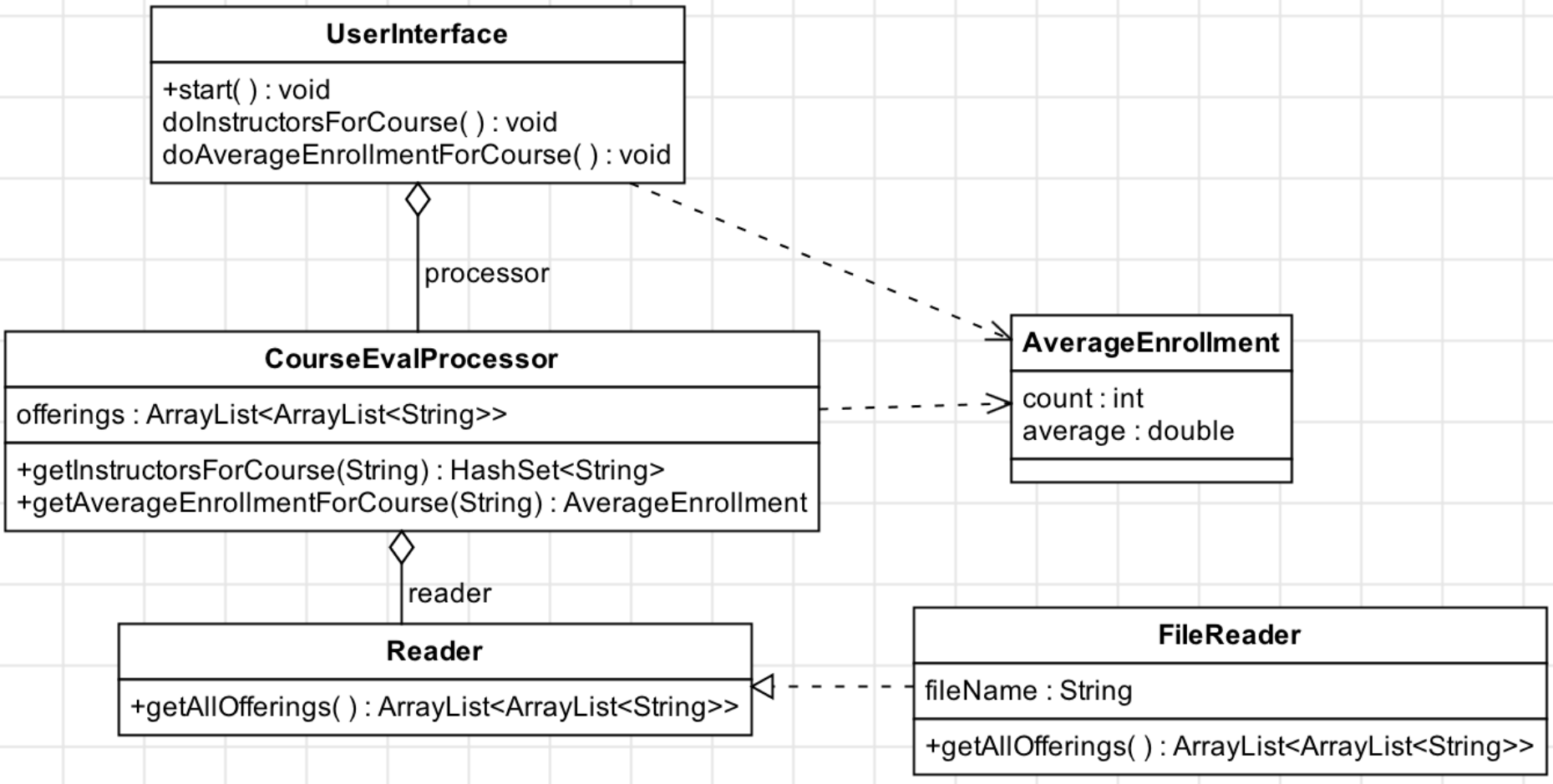


Abstraction for the Reader class

- CourseEvalProcessor shouldn't care or know that the Reader reads from a file, e.g.
  - specifying file name
  - catching file I/O exceptions
  - accessing the File or InputStream object
  - calling methods in Reader like "openFile"

- Reader should be designed in such a way that its **implementation** can change without changing its **interface**

How can we further improve abstraction?



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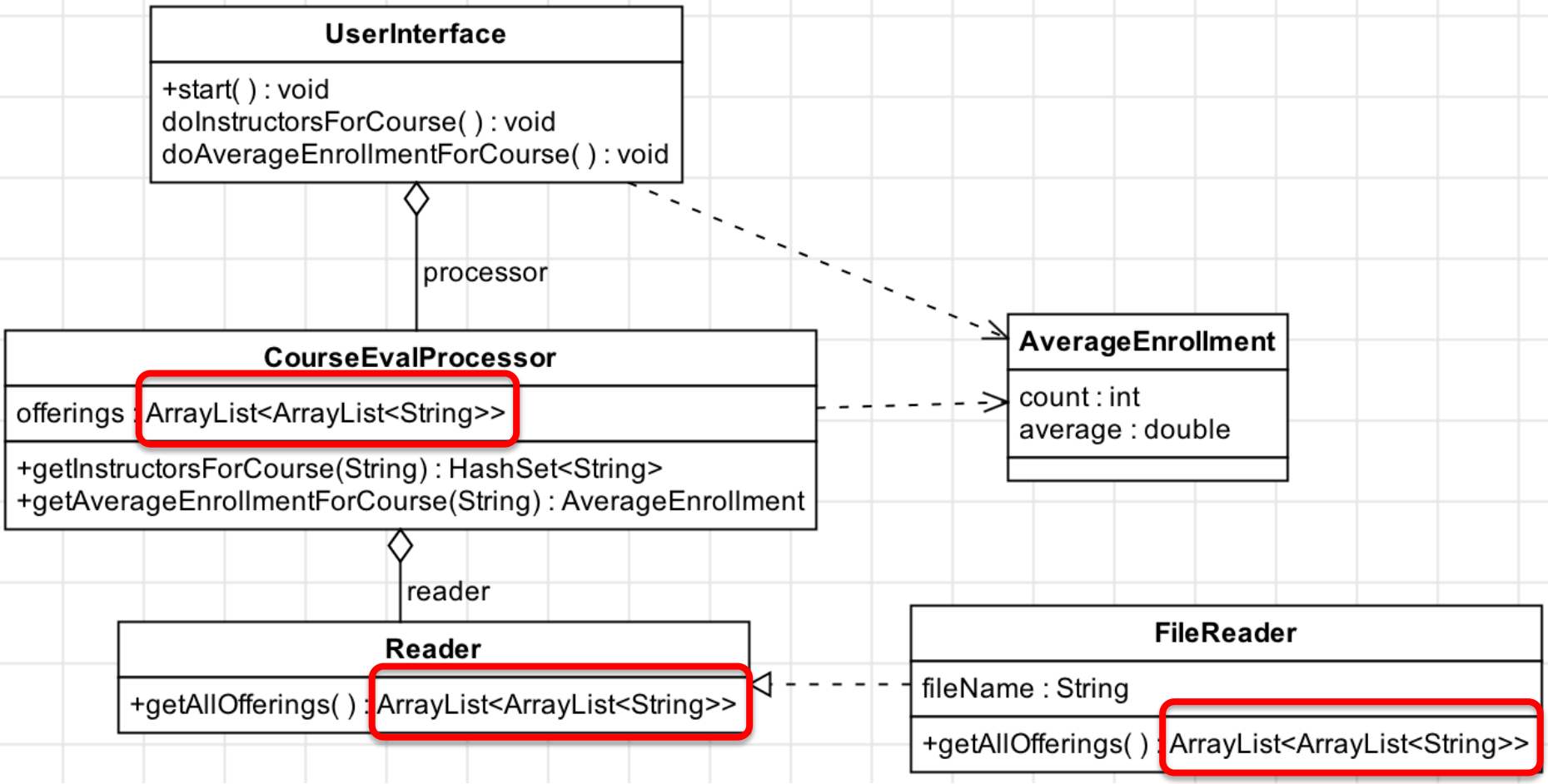
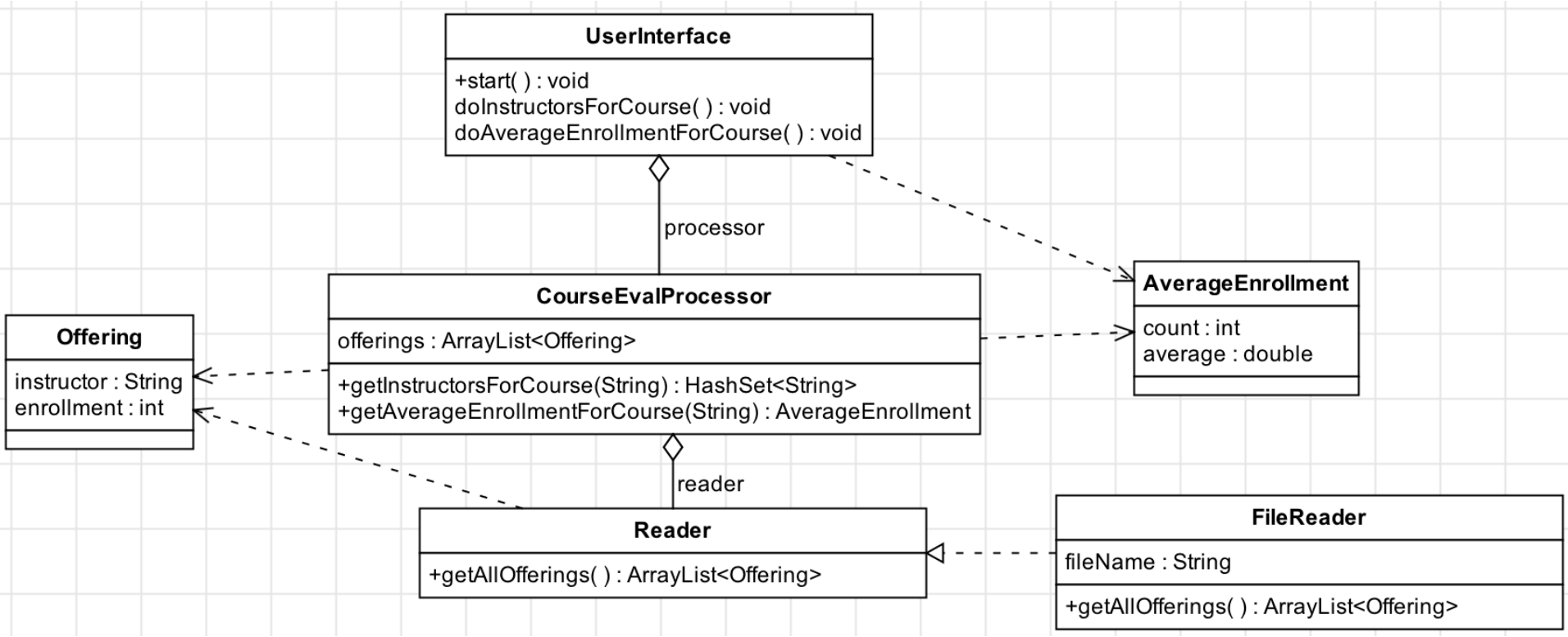


Use custom classes as needed



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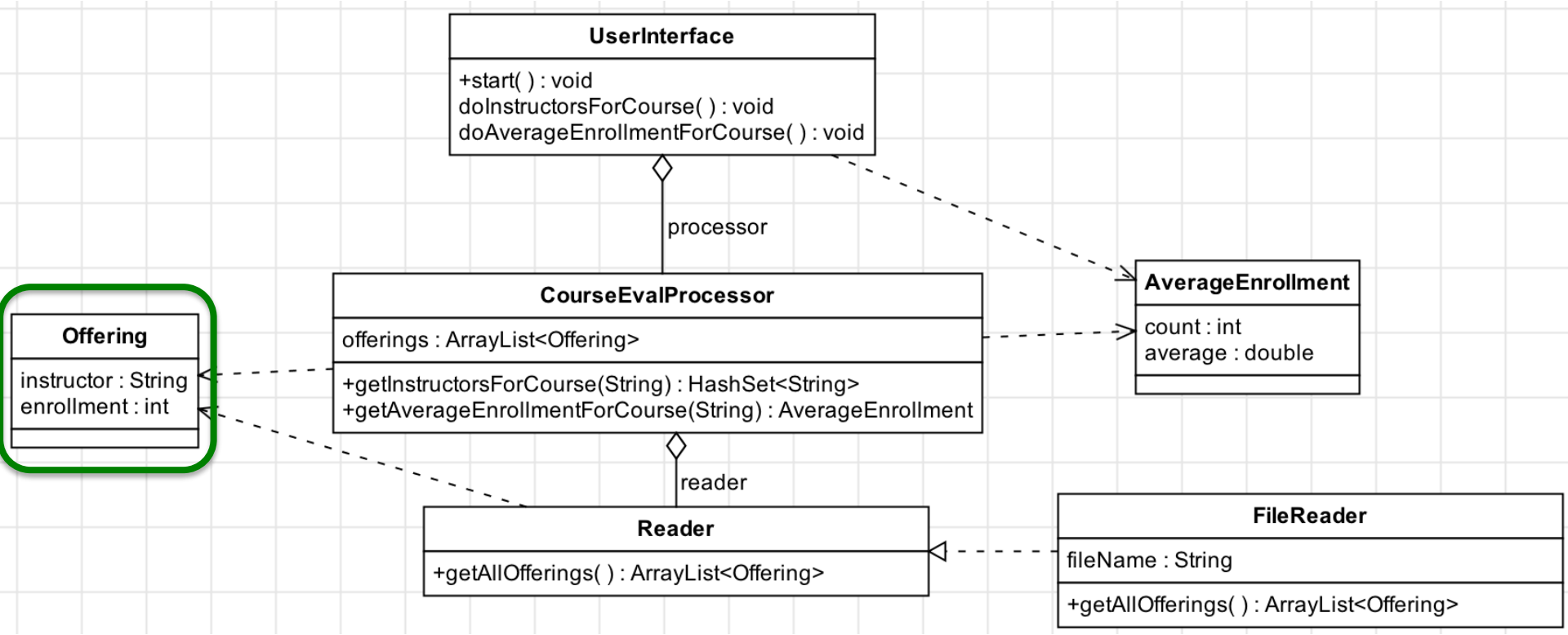

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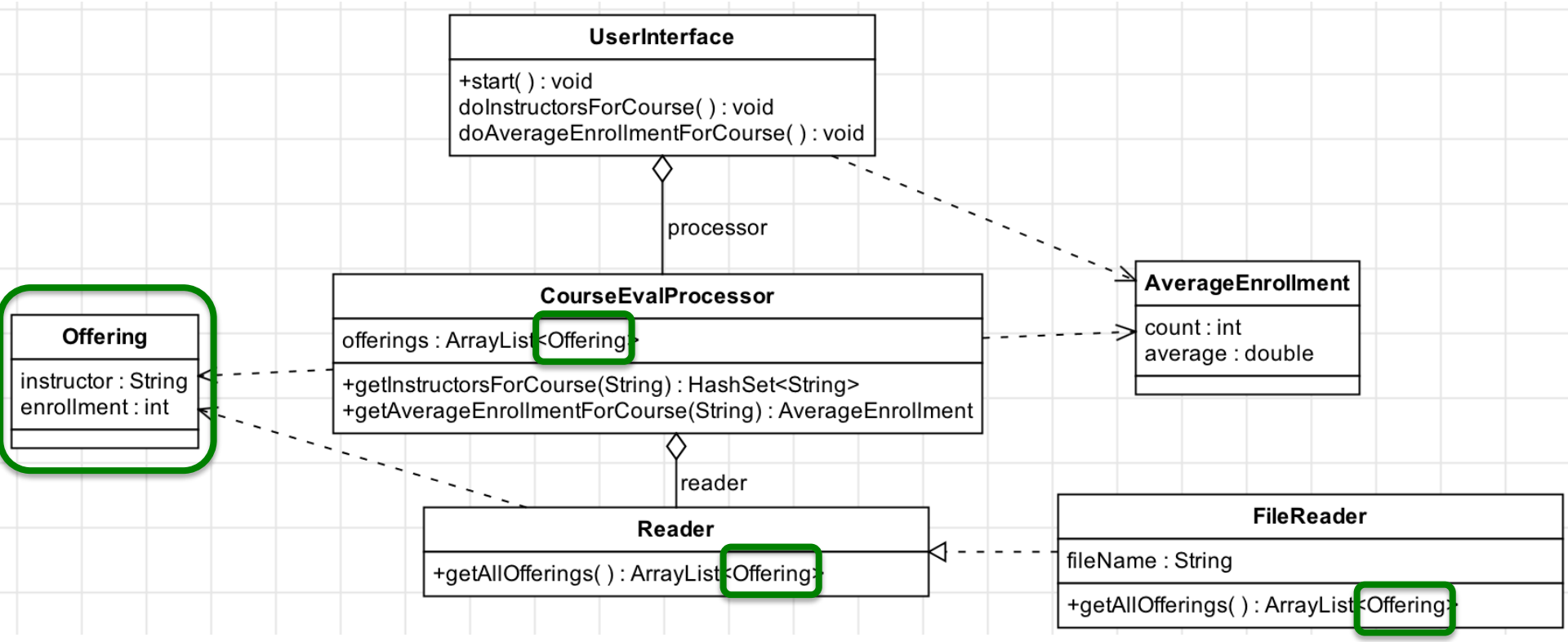

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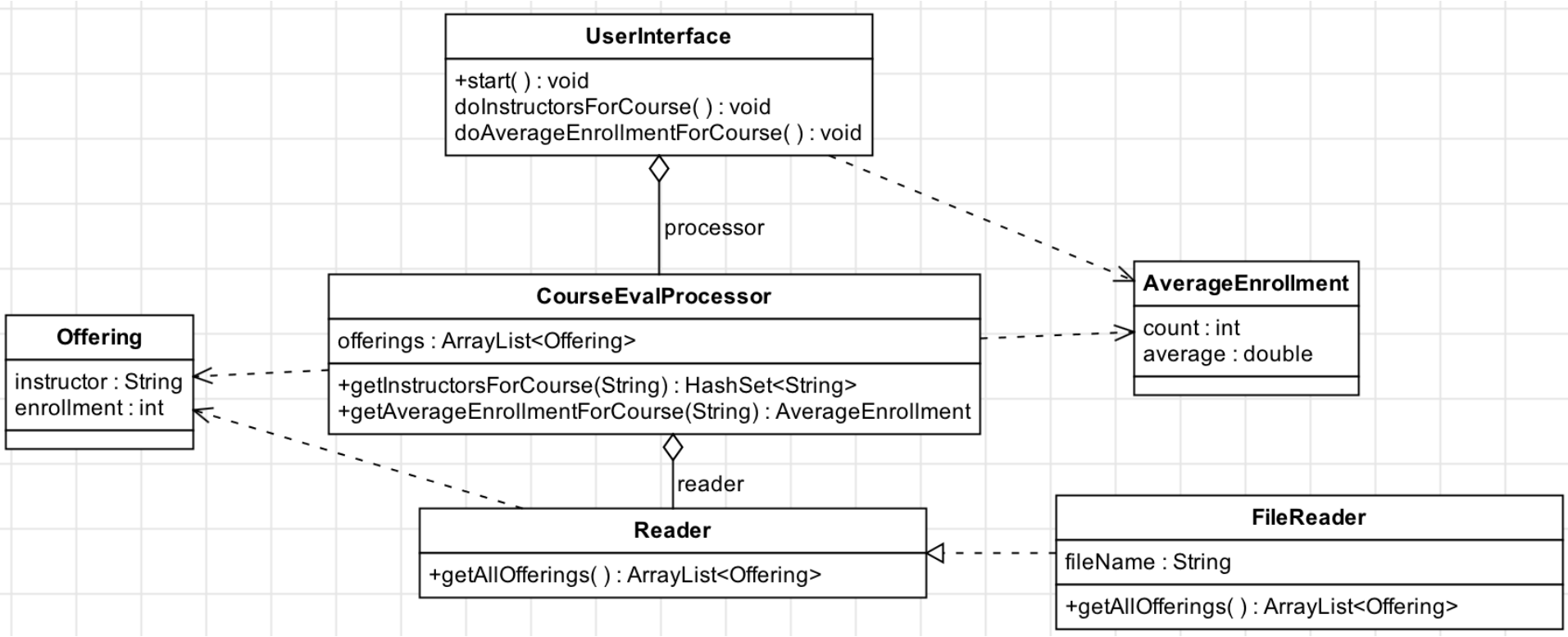
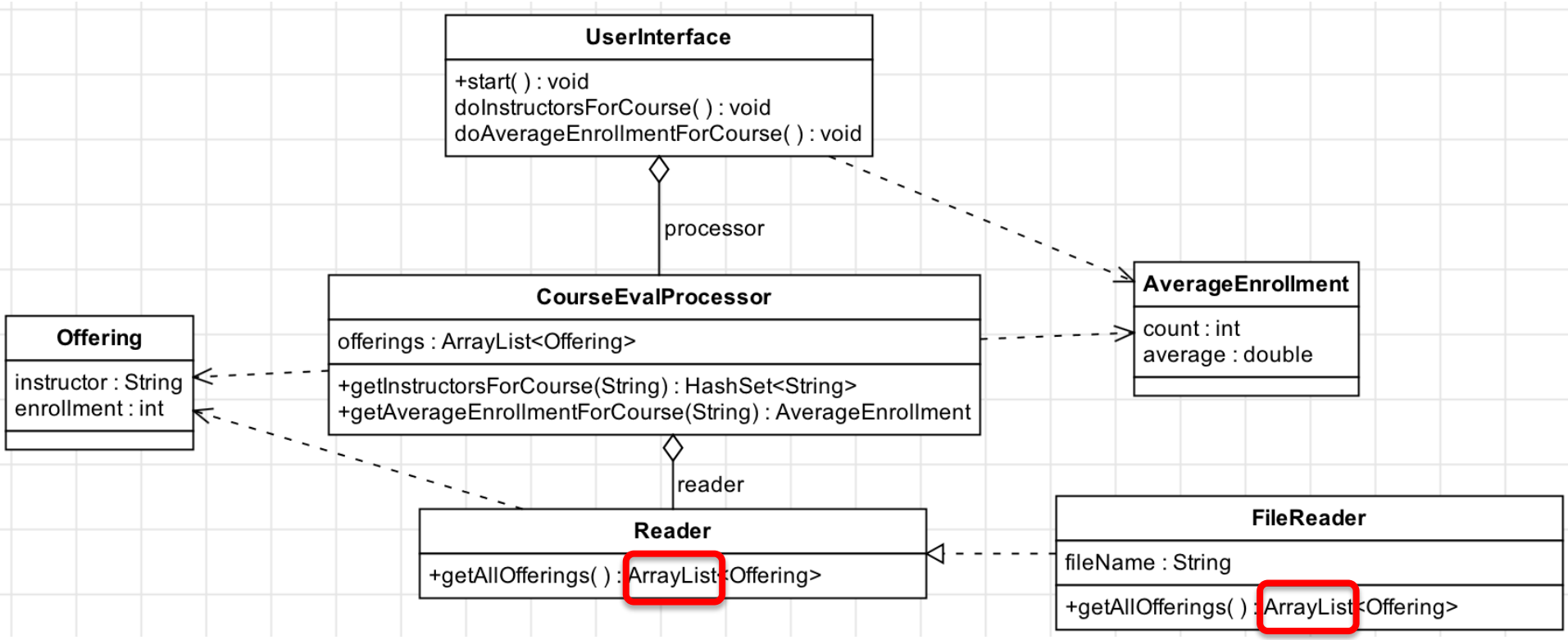


Use abstract data types classes as needed



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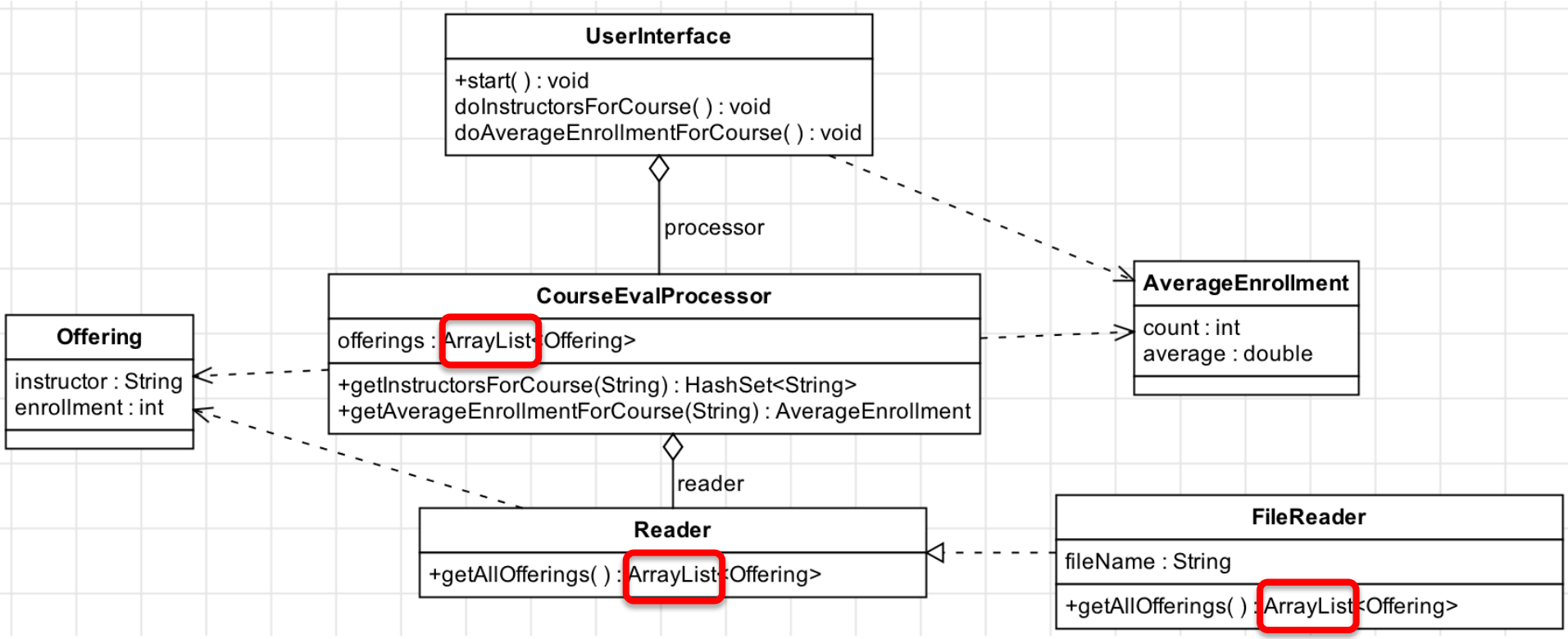

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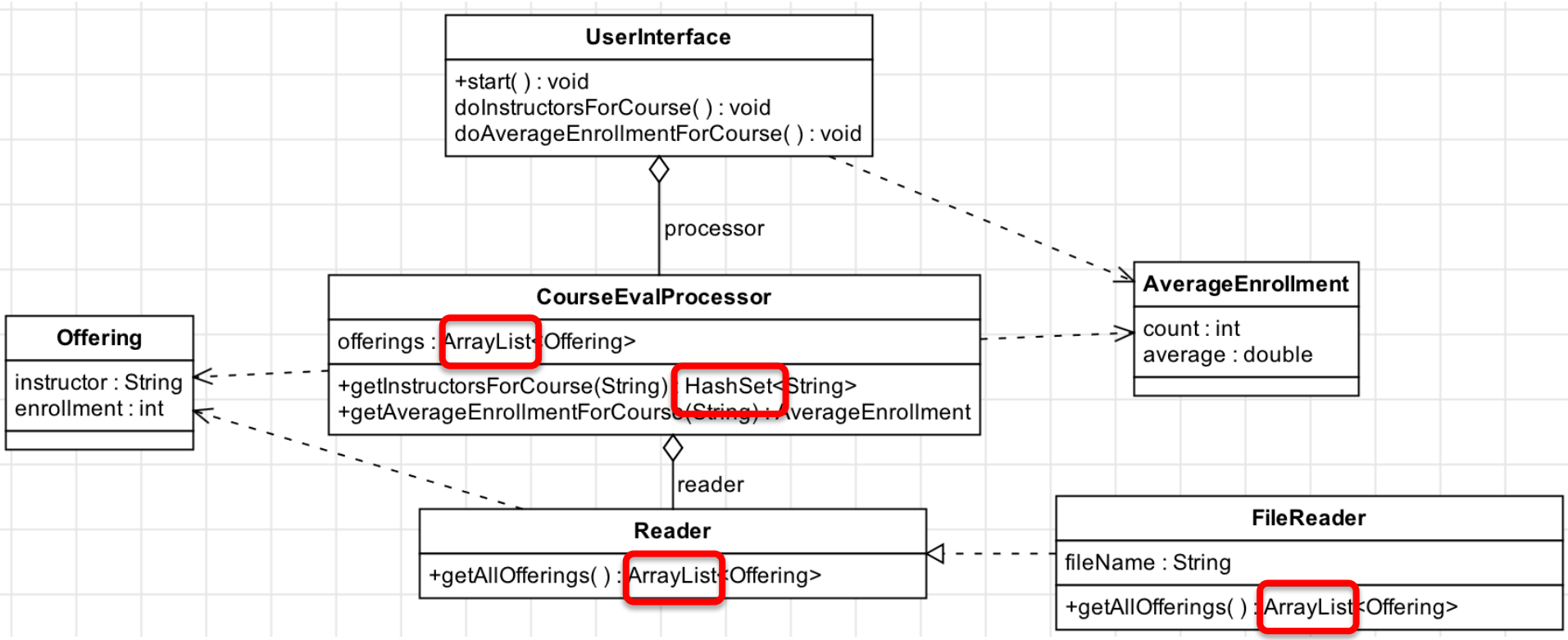

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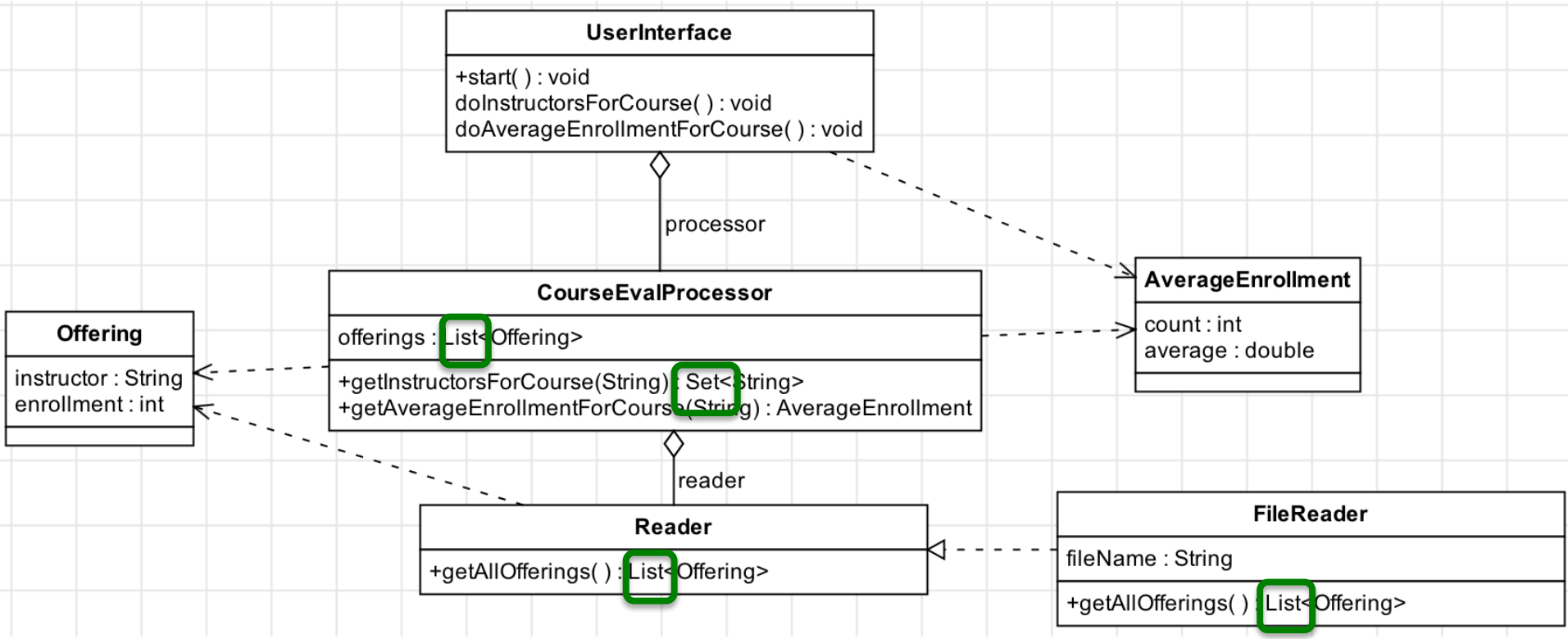

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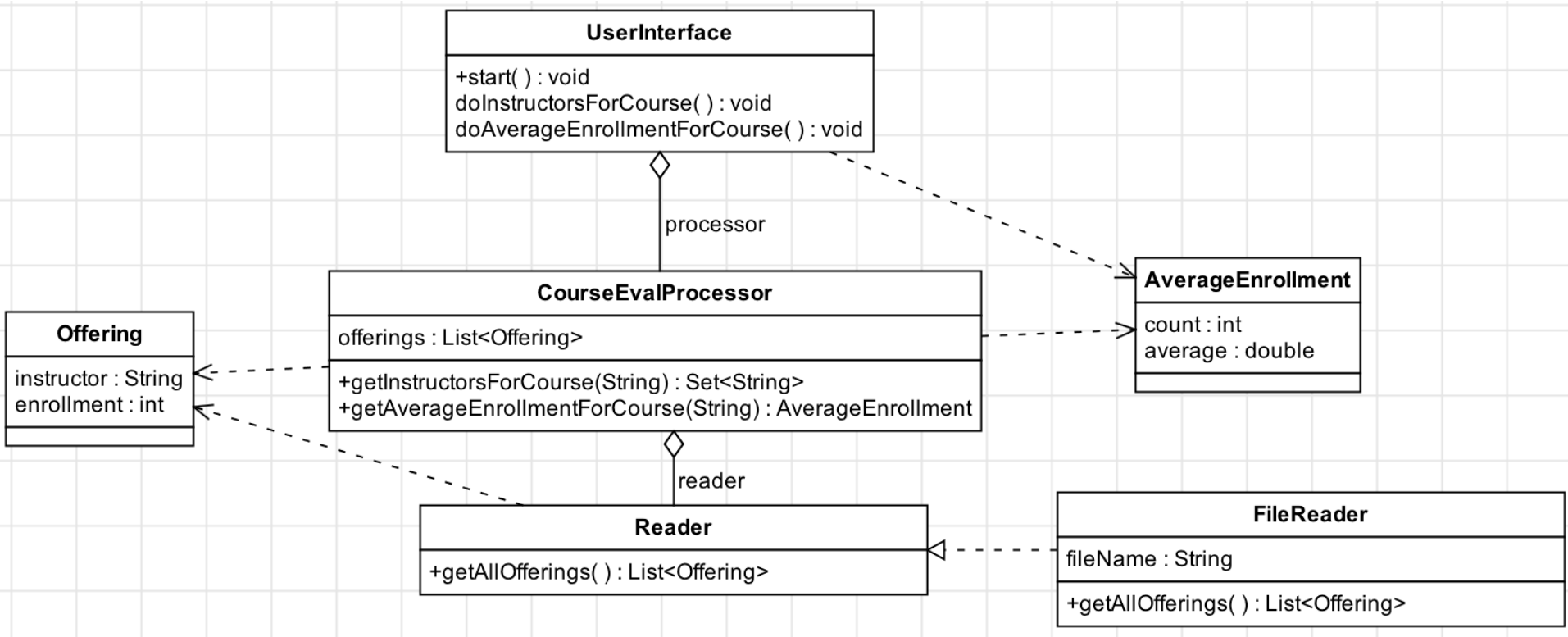

Abstraction in the Java API

- **Interfaces:** a class can have a dependency (field, parameter) on an interface without needing to know which class implements it

- **Abstract Data Types:** Set, List, Map, etc. in the Java Collections API

- **Design Patterns:** Observer

Recap: Abstraction

- A module can use other modules with minimal knowledge of the details of their implementation
- Should only care *what* they do (services they provide) and not *how* they do it

- **“Program to an interface, not an implementation”**
- Use custom classes as needed
- Use abstract data types when possible

SD2x3.10

Law of Demeter

Chris

Software Design Concepts

Modularity

Functional Independence

Abstraction

Software Design Concepts

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Abstraction

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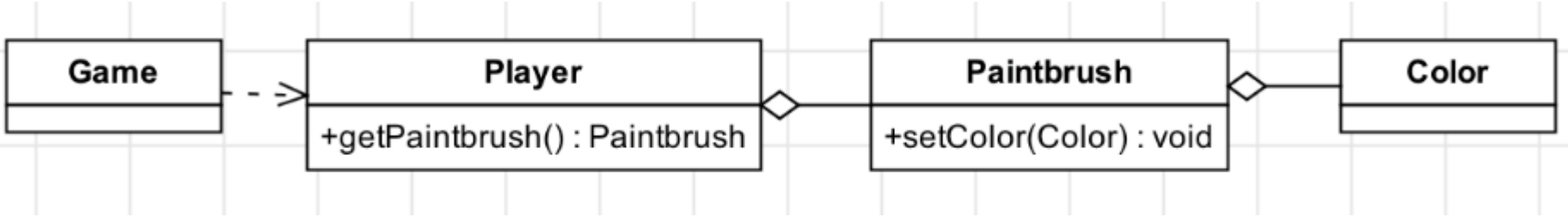
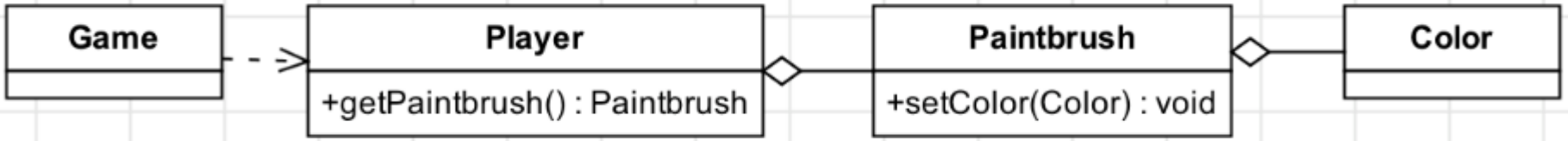

Game
Player
+getPaintbrush() : Paintbrush
Paintbrush
+setColor(Color) : void
Color




```
public class Game {

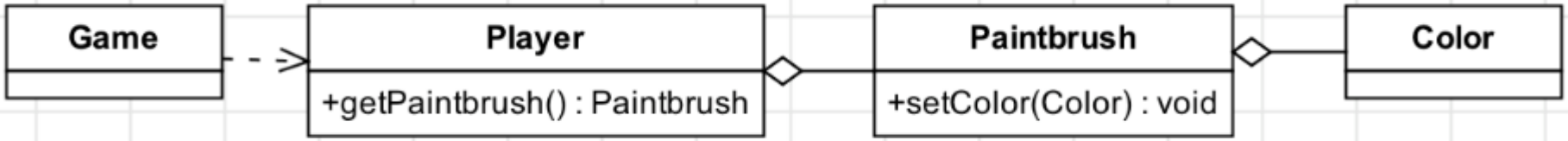
    . . .

    protected void updatePlayer(Player player) {

        . . .

        player.getPaintbrush().setColor(Color.RED);

        . . .
```

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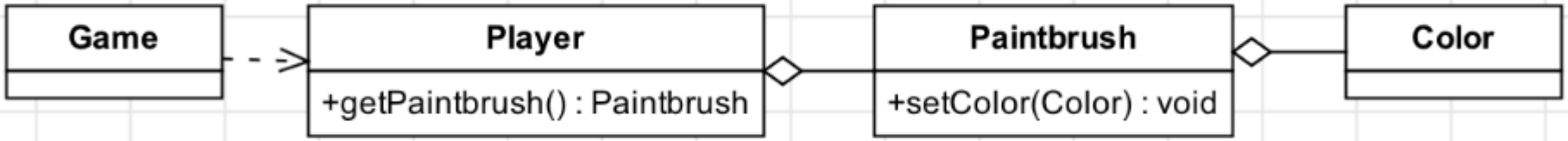


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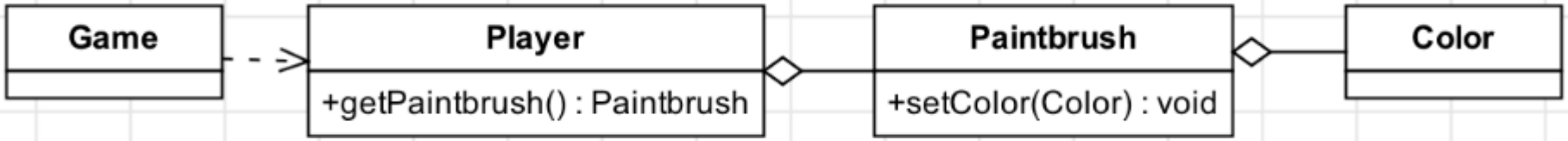


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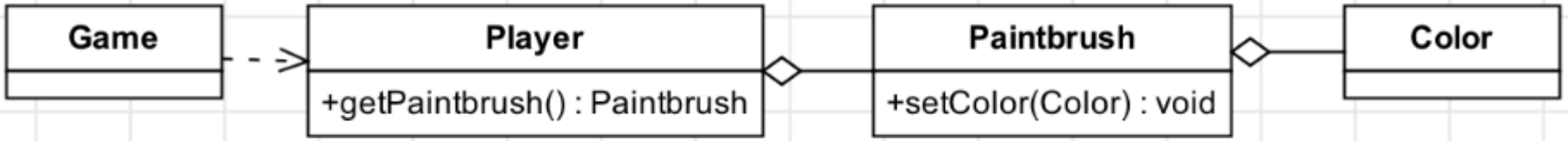
Law of Demeter

- Also known as the **“Principle of Least Knowledge”**
- Named after the Greek goddess of agriculture
- “A module should be able to perform its tasks with (minimal) knowledge of related modules, and with no knowledge of the modules related to those”
- “Don’t talk to strangers”

Law of Demeter

- A method **M** in object **O** may only invoke methods on the following:
  - the object **O** itself
  - parameters to **M**
  - objects created in **M**
  - **O**'s fields
  - global variables

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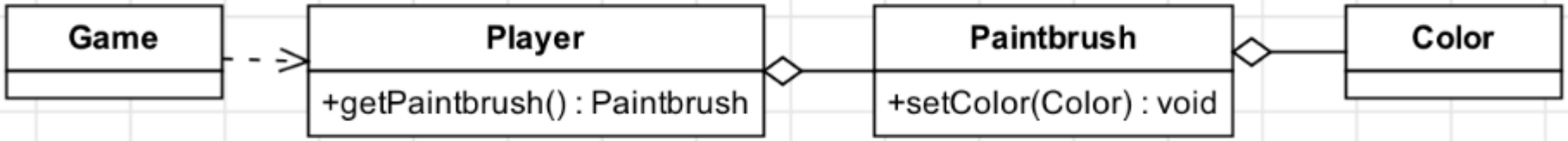
        . . .
```




```
public class Game {

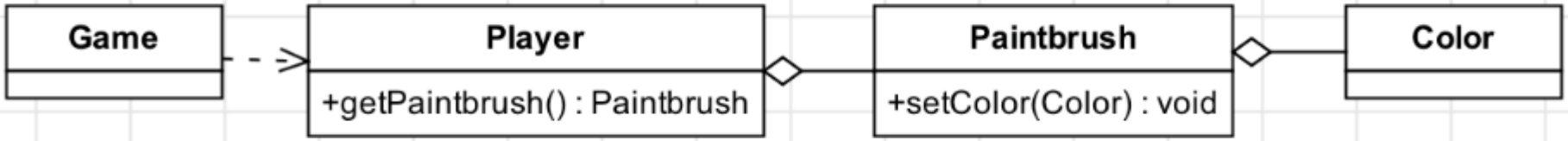
    . . .

    protected void updatePlayer(Player player) {

        . . .

        player.getPaintbrush().setColor(Color.RED);

        . . .
```

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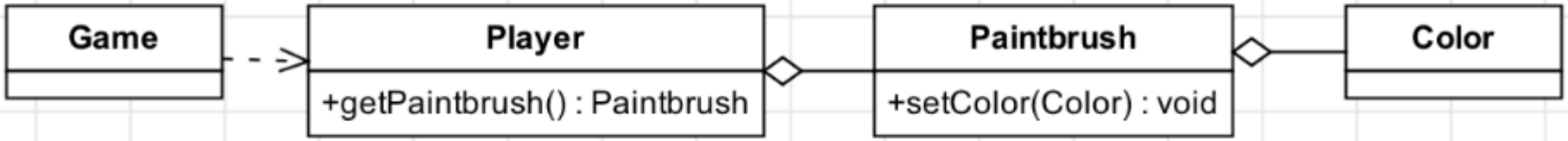


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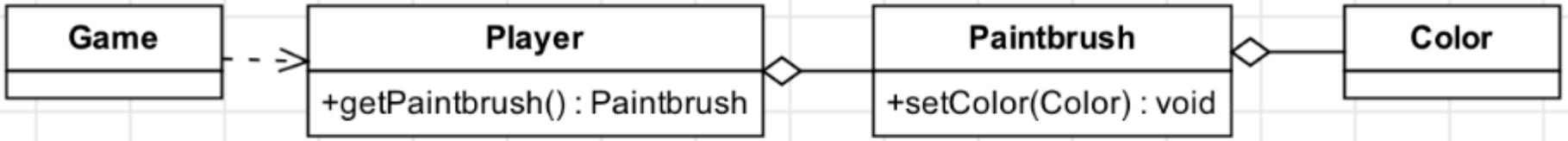
```



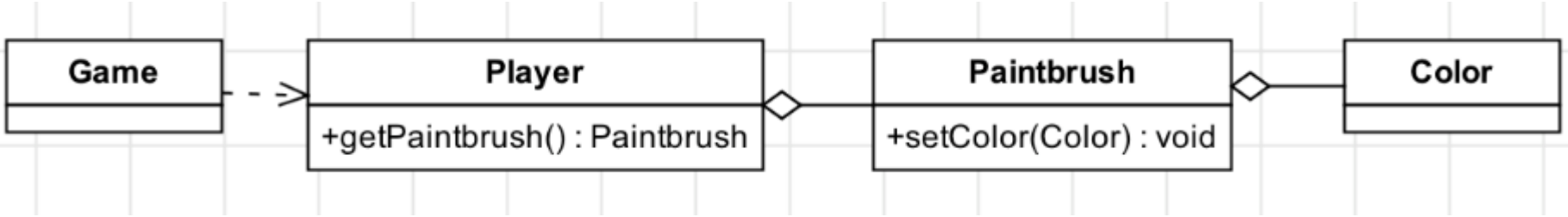

```
public class Game {

    . . .

    protected void updatePlayer(Player player) {

        . . .

        Paintbrush brush = player.getPaintbrush();
        brush.setColor(Color.RED);
        . . .
```



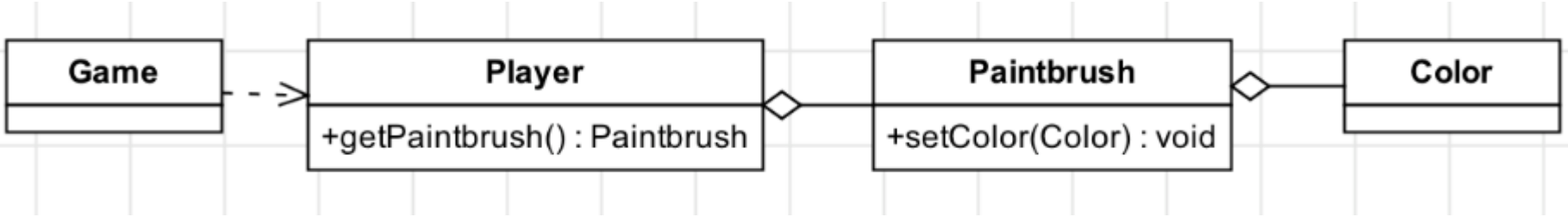

```
public class Game {

    . . .

    protected void updatePlayer(Player player) {

        . . .

        Paintbrush brush = player.getPaintbrush();
        brush.setColor(Color.RED);
        . . .
```



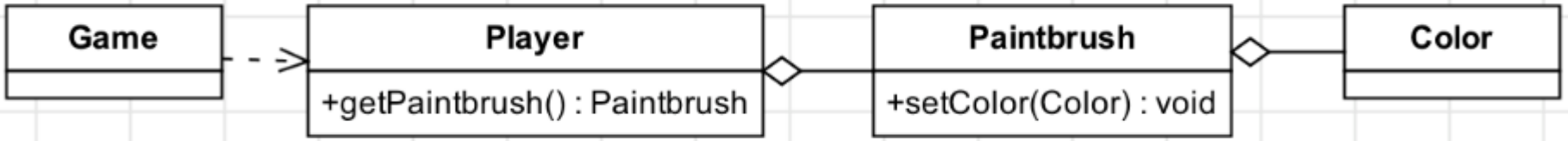

```
public class Game {

    . . .

    protected void updatePlayer(Player player) {

        . . .

        Paintbrush brush = player.getPaintbrush();
        brush.setColor(Color.RED);
        . . .
```

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public class Game {

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        . . .

        player.getPaintbrush().setColor(Color.RED);

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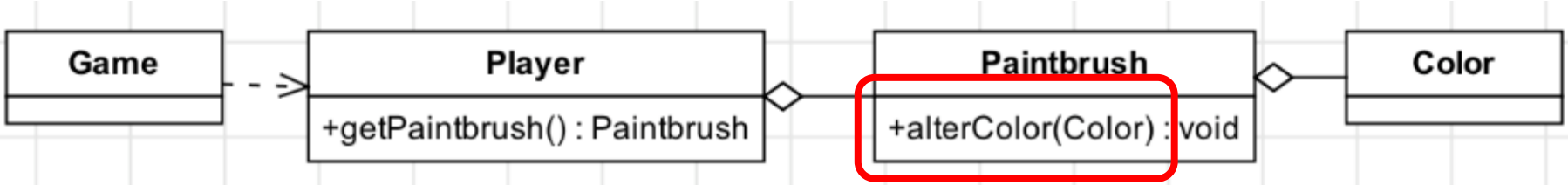
```

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public class Game {

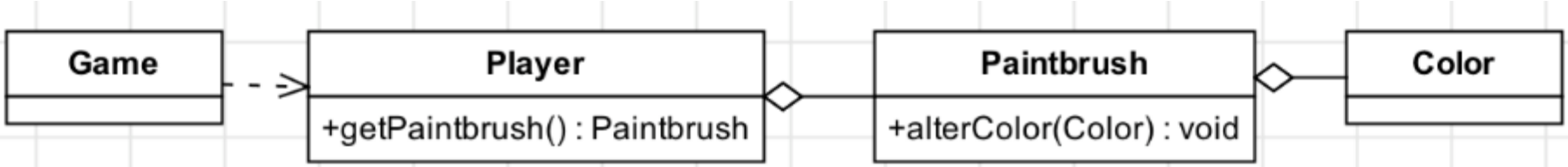
    . . .

    protected void updatePlayer(Player player) {

        . . .

        player.getPaintbrush().setColor(Color.RED);

        . . .
```




```
public class Game {

    . . .

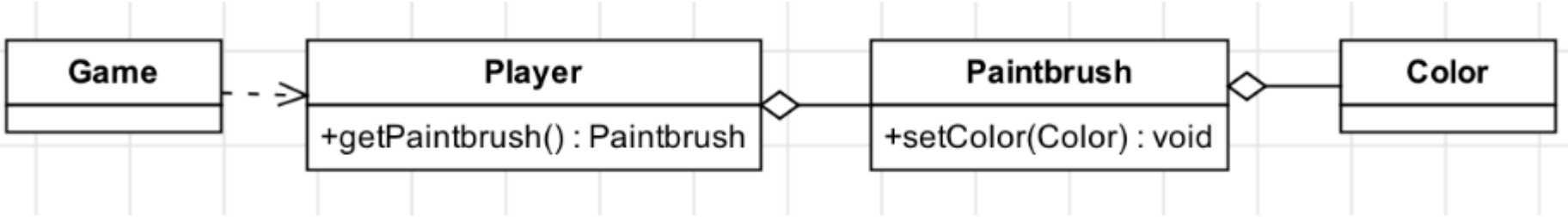
    protected void updatePlayer(Player player) {

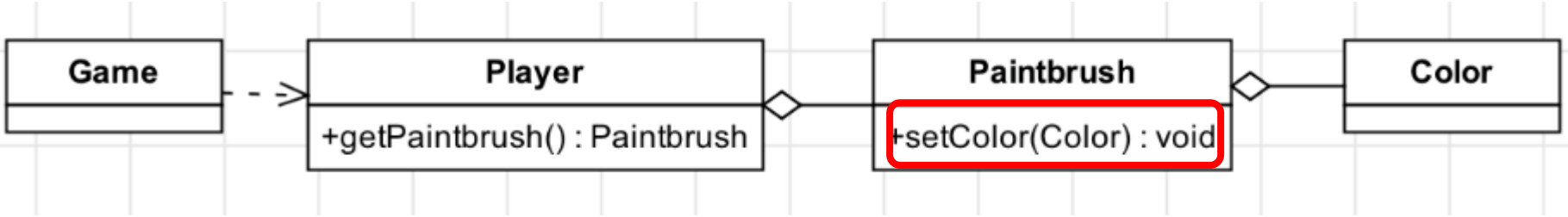
        . . .

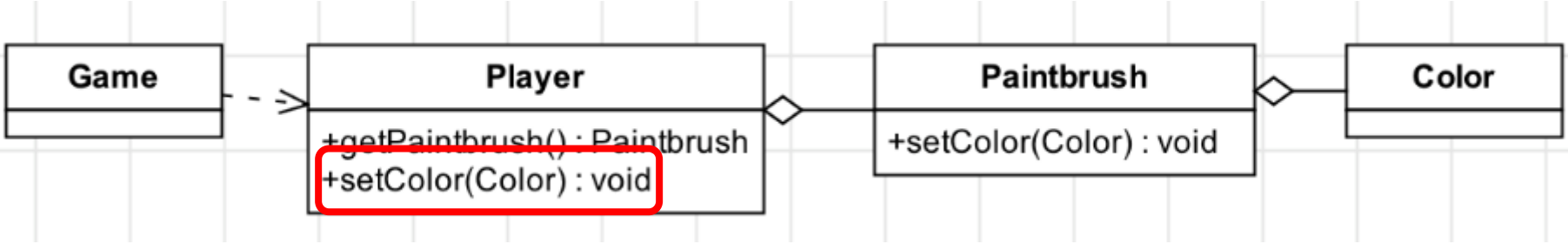
        player.getPaintbrush().setColor(Color.RED);

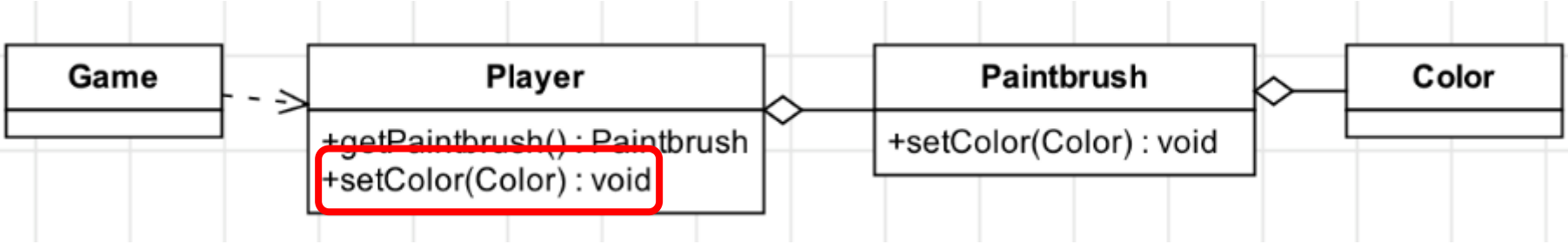
        . . .
```

Solution:
Hide Delegate

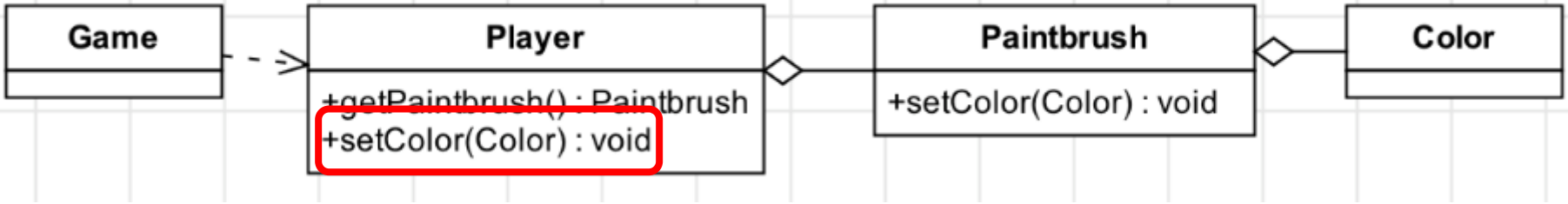

Game
Player
+getPaintbrush() : Paintbrush
Paintbrush
+setColor(Color) : void
Color


Game
Player
+getPaintbrush() : Paintbrush
Paintbrush
+setColor(Color) : void
Color

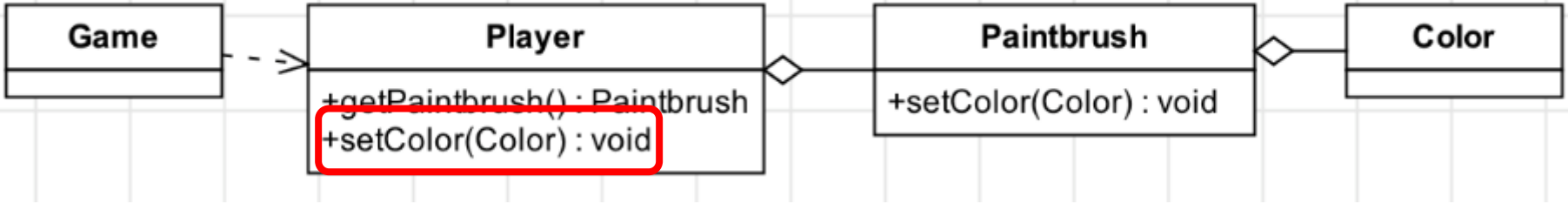

Game
Player
+getPaintbrush() : Paintbrush
+setColor(Color) : void
Paintbrush
+setColor(Color) : void
Color



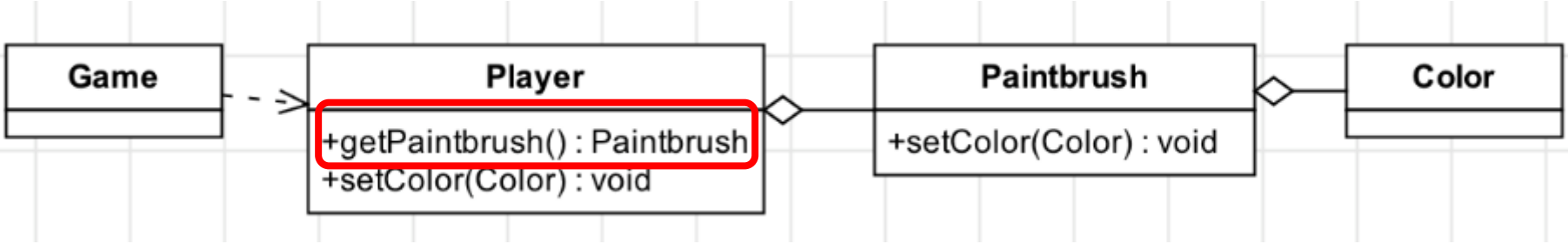

```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```




```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```




```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
        paintbrush.setColor(color);
    }
    . . .
}
```



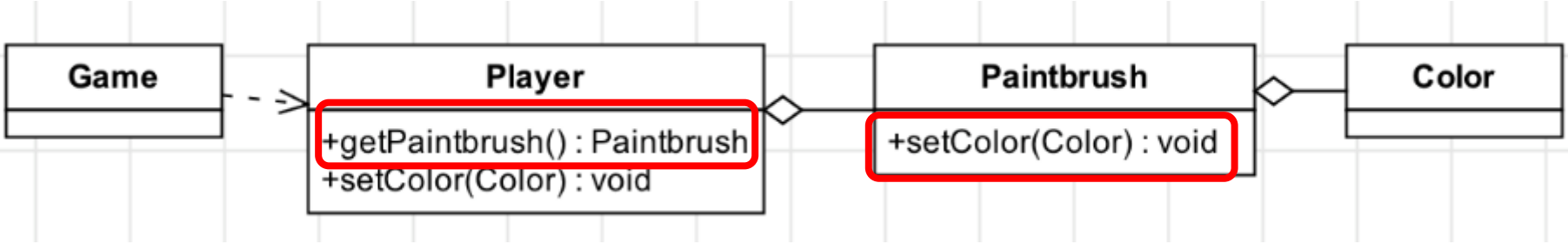

```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```

```
public class Game {
    . . .

    protected void updatePlayer(Player player) {
        . . .

        player.getPaintbrush().setColor(Color.RED);

        . . .
```



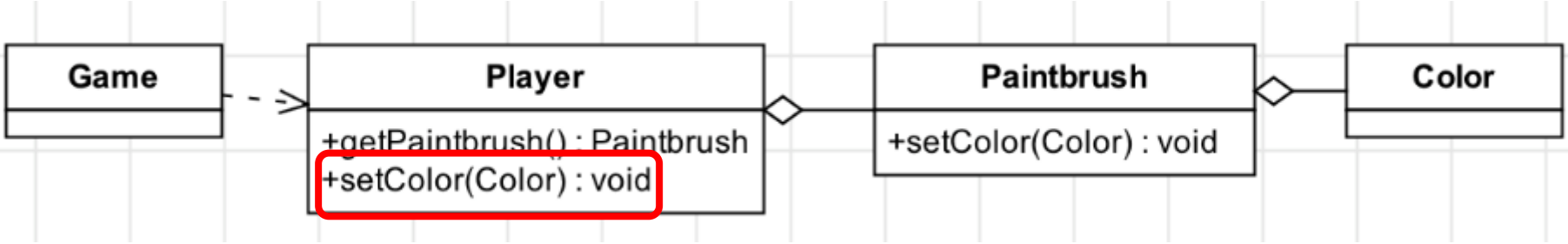

```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```

```
public class Game {
    . . .

    protected void updatePlayer(Player player) {
        . . .

        player.getPaintbrush().setColor(Color.RED);

        . . .
```



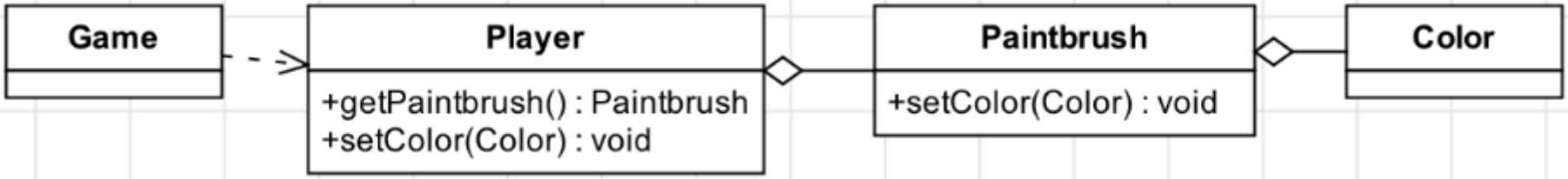

```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```

```
public class Game {
    . . .

    protected void updatePlayer(Player player) {
        . . .

        player.setColor(Color.RED);

        . . .
```



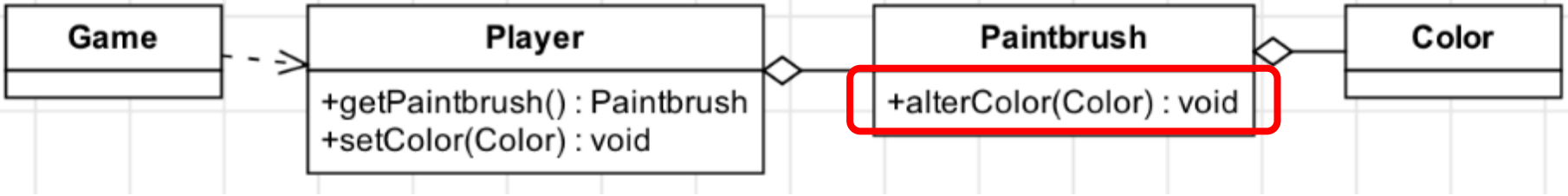

```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```

```
public class Game {
    . . .

    protected void updatePlayer(Player player) {
        . . .

        player.setColor(Color.RED);

        . . .
```



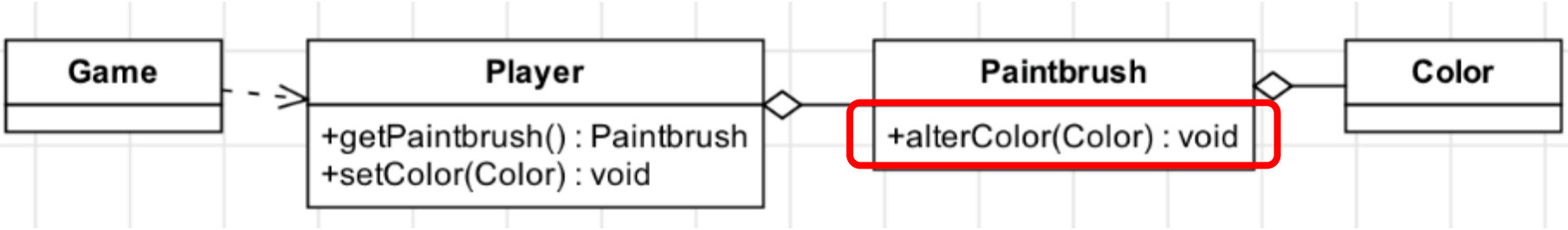

```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.setColor(color);
    }
    . . .
}
```

```
public class Game {
    . . .

    protected void updatePlayer(Player player) {
        . . .

        player.setColor(Color.RED);

        . . .
```




```
public class Player {
    . . .
    private Paintbrush paintbrush;
    public void setColor(Color color) {
         paintbrush.alterColor(color);
    }
    . . .
}
```

```
public class Game {
    . . .

    protected void updatePlayer(Player player) {
        . . .

        player.setColor(Color.RED);

        . . .
```

Recap

- Try to avoid **Message Chains** in your code
- Be careful about violating the **Law of Demeter**
- Use the **Hide Delegate** pattern
- This will help improve **abstraction**

Recap: Software Design

- **Internal Quality:** Changeability, Stability, Analyzability, Testability

- **Design Concepts:** Modularity, Functional Independence, Abstraction