

CH1 - Introduction

- **Software:** Computer programs & associated documentation
 - **Software engineering:** concerned with theories, methods, tools for software development
 - Fundamental activities: software specification, development, validation, evolution
 - A part of system engineering (hardware + software + process engineering)
 - Often: Software costs > computer system / hardware cost
 - Software maintenance cost > development cost
 - Software products: "Generic" or "customized"
 - Essential attributes of good software:
 - **Maintainability:** Critical attribute. To be able to evolve with changing needs
 - **Dependability:** Security, reliability, safety. Should not cause damage in case of failure
 - **Efficiency**
 - **Acceptability:** Compatible with other systems, understandable, usable
-

Application Types

Stand-alone

- Run on a local machine (e.g a PC).
- Need not to be connected to a network
- Has all required functionality

Interactive transaction-based

- Accessed by users externally, runs on remote computer
- Web app.s (e.g e-commerce app.s)

Embedded control systems

- Controls and manages HW

Batch processing systems

- Processes individual inputs in large batches

Data collection systems

- Collect data using sensors, send to other systems to process

Entertainment systems

Modelling & simulation systems

- Developed by scientists & engineers for modeling
- Usually includes many separate interacting objects

Systems of systems

- Composed of other software systems

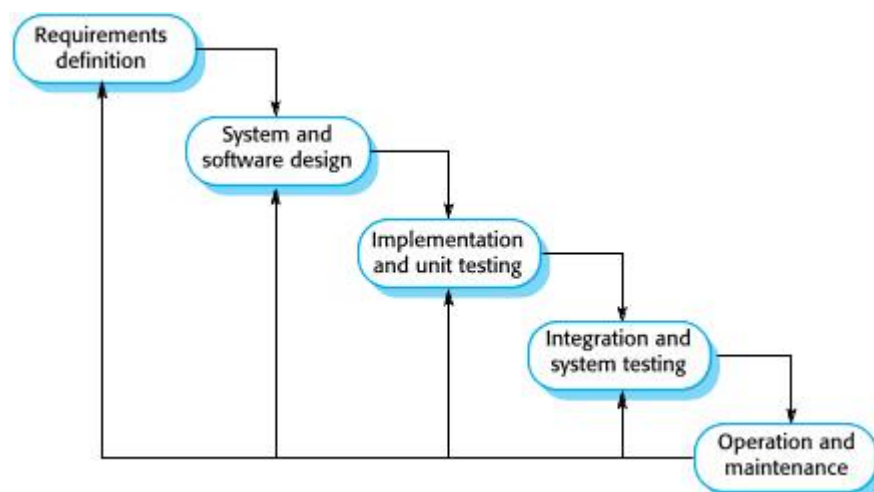
-
- Web-based systems: Distributed & complex. Need "agile development": impractical to specify all the requirements for such systems in advance.
 - Service-oriented systems: All components considered as replaceable services. Allows rapid configurations & incremental updates as new services become available.

CH2 - Software Processes

- "Software process": Structured set of activities required to develop a software system
- Many different ones but all involve: Specification, design & implementation, validation, evolution
- Approaches:
 - "Plan driven process": all activities planned in advance, progress is measured against the plan
 - "Agile process": Incremental planning, easier to change process to changing requirements
 - Often, elements from both approaches are used.

Software Process Models

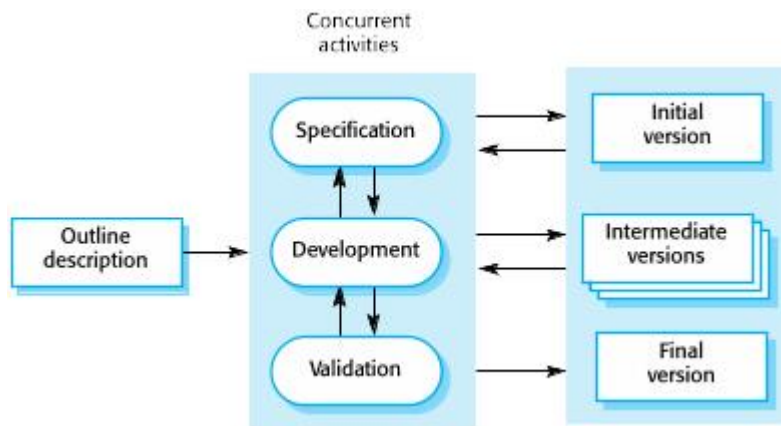
The Waterfall Model



- Plan-driven

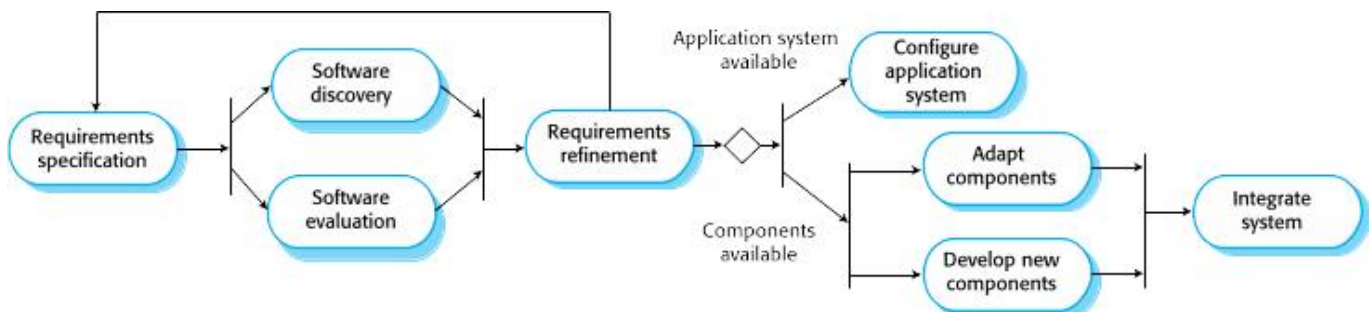
- Separate identified phases
- Drawback: a phase has to be completed before moving onto next, hard to accomodate changes
 - Only appropriate when the requirements are well understood & changes will be limited
- Mostly used for large system engineering projects where a system is developed at several sites

Incremental Development



- Cost of making changes reduced
- Easier to get customer feedback
 - Customers can comment on demonstrations
 - Customers can be provided with useful software earlier
- Drawbacks:
 - Regular changes may corrupt project structure - incorporating changes becomes harder and costlier as time progresses
 - Cost-ineffective to document each system version -> Measuring progress is hard

Integration & Configuration (Reuse-oriented SW. Eng.)



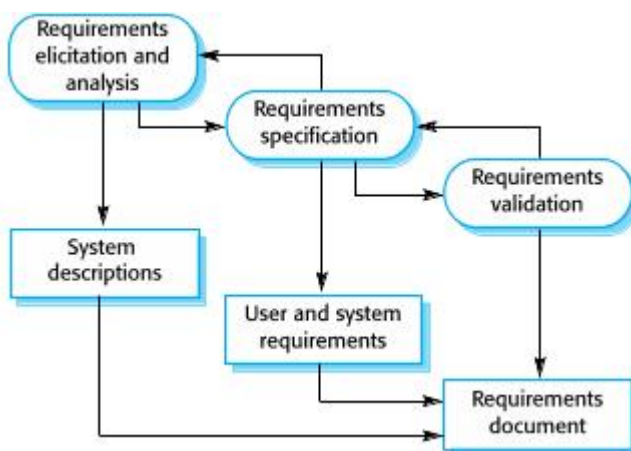
- Based on software reuse - reused elements can be configured according to requirements

- Standard approach for many business system types
- Faster delivery
- Less SW developed from scratch -> Reduced risks & costs
- Drawbacks:
 - Some requirements are likely to be unsatisfied
 - Lost control over the evolution of reused components

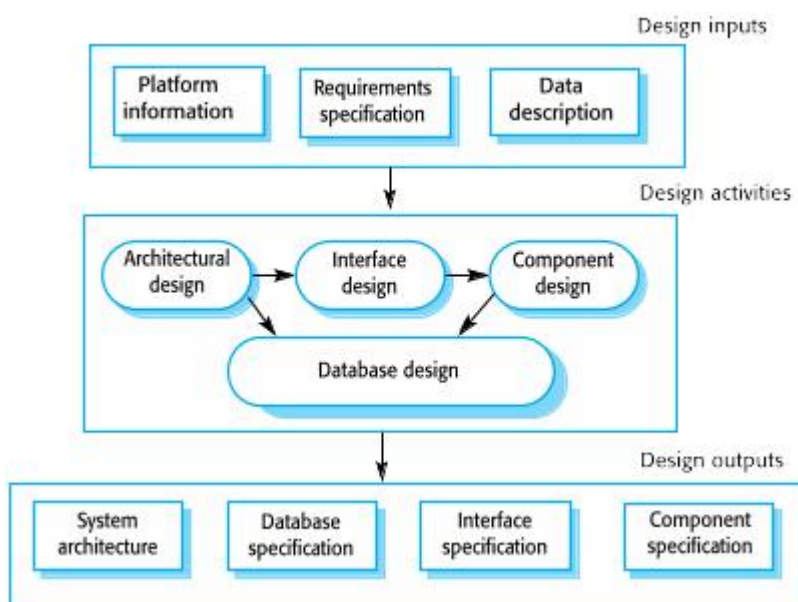
Process Activities

- Can be ordered sequentially or interleaved according to the model

Requirements Engineering Process



Software Design & Implementation



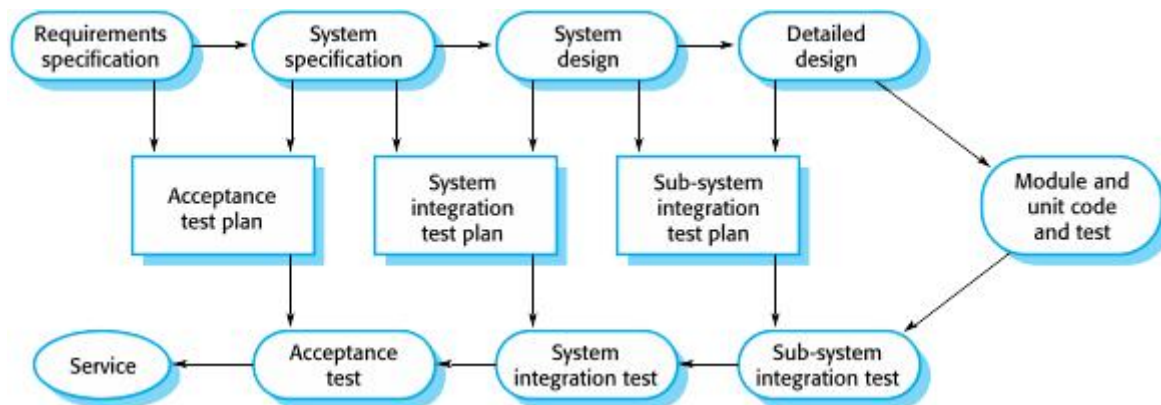
- Design: Creating software structure
 - Architectural, database, interface (between components), component selection & design
- Implementation: translating the structure into an executable
 - Design & implementation can be closely related or interleaved

Software Validation

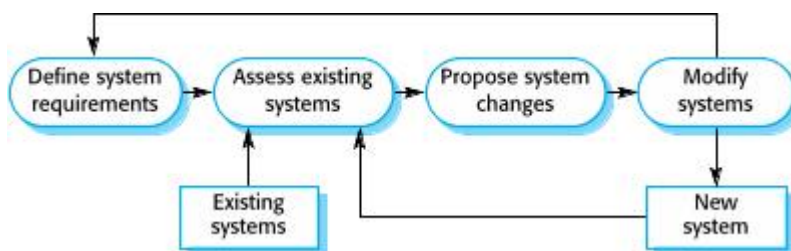
- Testing: Most common verification & validation activity



- V-model: Testing phases in a plan-driven software process:

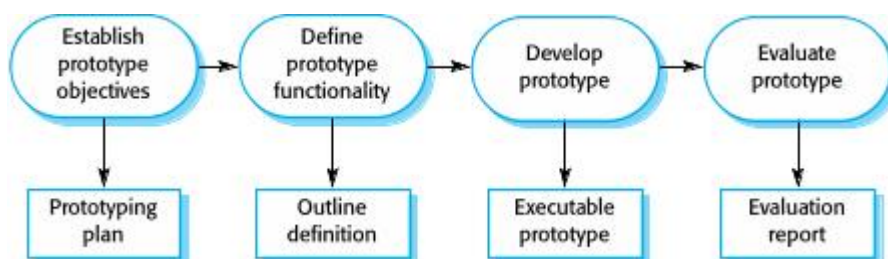


System Evolution



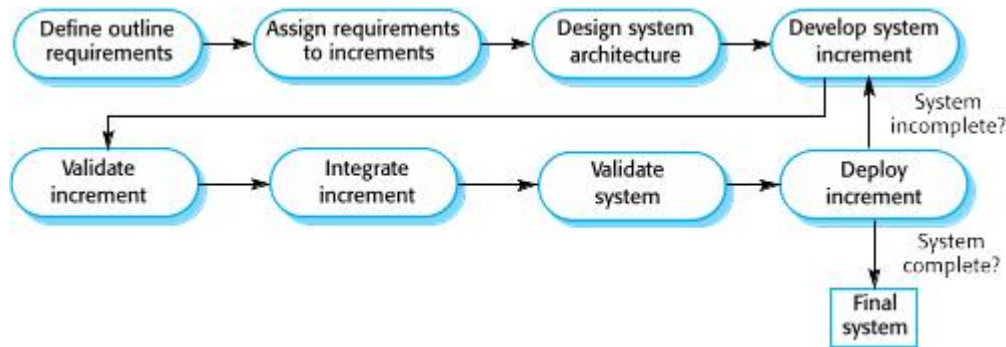
- Change anticipation: Possible changes can be anticipated without much rework
- Change tolerance: Process is designed so that changes are applied without much cost

Software Prototyping



- Discarded after development: usually unstructured, undocumented and not standard-compliant

Incremental Development & Delivery



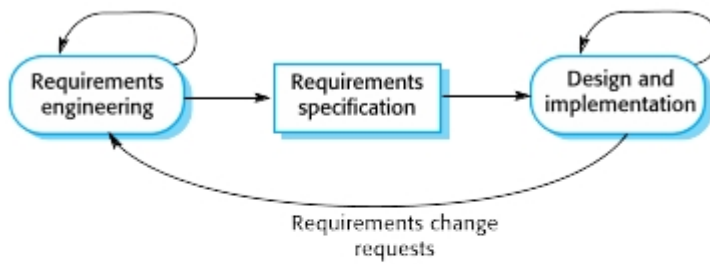
- Early increments serve as prototypes
- Requirements are not changed throughout the development of an increment
- Highest priority services receive most testing
- Specification is developed together with the SW itself
 - May contradict procurement models of some organizations

Process Improvement

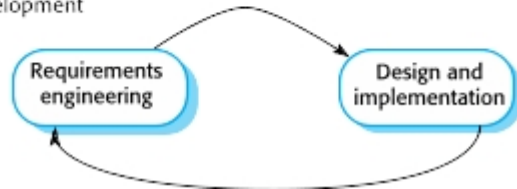
- Process maturity approach: ? Agile approach: focus on iterative development & reduction of overheads. Emphasis on rapid functionality delivery & adapting to requirement changes
- improvement cycle: Change -> Measure -> Analyze -> Change ...
- Process metrics:
 - Taken time to complete activities
 - Required resources for activities
 - Number of occurrences of a specific event (e.g. an error)
- SEI capability maturity model:
 1. Initial: uncontrolled
 2. Repeatable: Defined & used product management procedures
 3. Defined: Defined & used process management procedures
 4. Managed: Defined & used quality management strategies
 5. Optimising: Defined & used process improvement procedures

CH3 - Agile SW Development

Plan-based development



Agile development



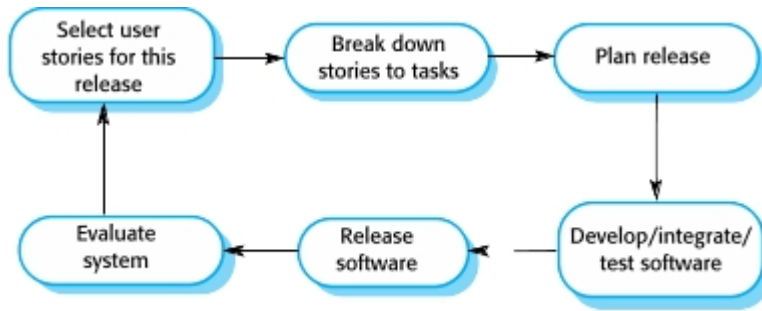
- Program specification, design and implementation are inter-leaved
- The system is developed as a series of versions or increments with stakeholders involved in version specification and evaluation
- Frequent delivery of new versions for evaluation
- Extensive tool support (e.g. automated testing tools) used to support development.
- The aim is to reduce overheads in the SW process, to be able to respond quickly to changing requirements without excessive rework.
 - e.g Minimal documentation - focus on working code

Principles

- Customer involvement: Evaluating iterations, provide and prioritize requirements
- Incremental delivery
- People over processes: Skill of the team should be recognized - members should develop their own ways of working without prescribed processes
- Embrace change
- Maintain simplicity

Agile development techniques

Extreme programming (XP)

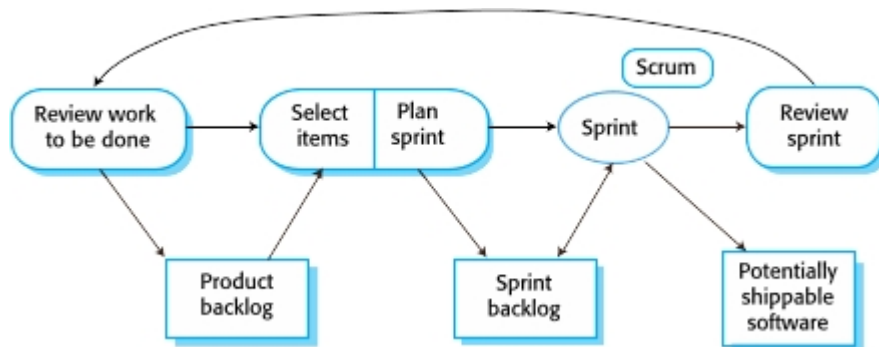


- "Extreme" iterative development:
 - New versions may be built several times per day
 - Increments are delivered to customers every 2 weeks
 - All tests must be run for every build and the build is only accepted if tests run successfully.
- Has a technical focus - usually not easy to integrate with management practice
- XP practices:
 - Incremental planning: Requirements recorded onto "story cards" -> Broken down into "Tasks"
 - Minimal useful set of functionality is developed first, frequent small releases. Functionality added incrementally.
 - Minimum design to satisfy current requirements is carried out
 - Test-first development: A functionality's test framework is implemented earlier than the functionality itself
 - Constant refactoring: All developers are expected to refactor code as soon as possible, even if there is no immediate need
 - Improves software understandability & reduces need for documentation
 - Well-structured code -> Changes are easier to make
 - Changes requiring architecture refactoring are much more expensive
 - Collective ownership: Everyone works on everything, no islands of expertise develop
 - Pair programming
 - Helps develop collective ownership
 - Informal review process
 - Encourages refactoring & sharing of knowledge
 - Continuous integration: After each task is completed, it is integrated & tested (must pass the test)
 - Test-driven development clarifies the requirements to be implemented
 - Tests are written as programs rather than data -> they can be executed automatically after integrating each new functionality
 - The customer should be available full-time as a member of the development team

- Customer may be reluctant - may feel that providing requirements was enough
- Large amounts of overtime are not acceptable: Reduces productivity & quality on long term

Agile Project Management

Scrum



- Agile method focusing on managing iterative development rather than agile practices
- "product backlog": a "TODO list", may be feature definitions, SW. requirements, user stories, supplementary tasks (e.g user documentation, architecture definition), etc.
- "scrum"s: daily meetings reviewing progress and daily tasks, ideally short f2f meeting including whole team
- "velocity": estimate of backlog covering rate of the team
- 3 phases:
 - Initial: plan outline, establish objectives (choose from backlog), design architecture
 - "Sprint cycles" of developing increments
 - fixed length (~2-4 weeks)
 - Project closure: wrap-up & complete documentation (e.g system help frames)
- Team is isolated from distractions & customer communication. Only the "scrum master" handles communication with the customer.
- Benefits:
 - Breaks down product into manageable chunks
 - Unstable requirements do not hold up
 - Whole team has visibility on everything
 - Customers see on-time increment delivery, can provide feedback
 - Establishes customer-developer trust

Scaling Up Agile Methods

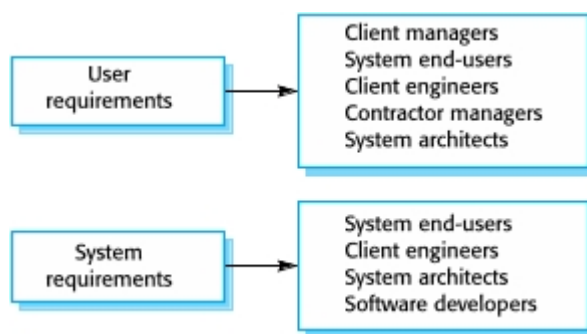
- Agile methods are successful for small & medium sized projects with small teams
 - "Scaling up": Agile methods for large SW systems with large teams
 - "Scaling out": Introducing agile methods to a large, experienced organization

Practical problems

- Agile is informal -> incompatible with legal approach to contracts in large companies
 - Agile is more appropriate for new software rather than maintenance
 - In large companies usually: Maintenance cost > development cost
 - Agile is more appropriate for small co-located teams
 - SW development involves worldwide distributed teams
 - Design documents may be needed for distributed teams
 - If not available: IDE support for visualisation & program analysis is essential
 - Cross-team communication mechanisms are needed
 - Agile works best when team has high skill level, but large companies have a wide range of skill level
 - Software contracts are based around specifications; however, agile interleaves specification and development
 - Contract based on time rather than functionality is required for agile -> considered risky
 - Maintenance problems:
 - Lack of SW documentation
 - Also needed if system is subject to external regulation
 - Customers are kept involved in development
 - Diverse set of stakeholders in large systems -> hard to involve them all in development
 - Need to keep the original team
 - Problem for long-lifetime systems
 - Prioritizing changes may be difficult: Multiple stakeholders have different priorities
 - Incremental delivery: Can be hard for business planning and marketing
-
- Several integrated systems: Significant amount of development on system configuration rather than development
 - Completely incremental approach to requirements engineering is impossible
 - Continuous integration practically impossible. However, frequent system builds & regular releases are essential
 - Multi-team Scrum:
 - Releases are aligned
 - Each team has their own scrum masters and product owners
 - Each team chooses "product architect"s to design & evolve overall system architecture
 - "scrum of scrums" are done where representatives of each team meet and discuss progress

Chapter 4 - Requirements Engineering

- Req. eng: Establishing services a customer requires from a system & its operation and development constraints
- System requirements: Descriptions of the system services & constraints. Generated during requirements engineering.
- "Requirement": Ranges from an abstract statement of a service / system constraint to a detailed functional specification
 - Dual function: May be the basis for a bid for a contract or for the contract itself
- User requirements: Statements in natural language + diagrams of services & operational constraints
 - Must be understandable by the end-users & customers without technical knowledge
- System requirements: Structured document, detailed descriptions of system functions, services, operational constraints.
 - Defines things to be implemented -> May be a part of a contract
- Readers of requirements specification types:



- "Stakeholder": Any person or organization who is affected by the system in some way and thus has a legitimate interest
 - End users, system managers, system owners, external stakeholders
- Agile methods use incremental requirements engineering and may express requirements as "user stories"
 - Practical for business systems
 - Problematic for systems requiring pre-delivery analysis (e.g critical systems) or systems developed by multiple teams

Functional & Nonfunc. Requirements

- **Functional requirements:** Statements of system services, describing system's reactions to particular inputs and situations
 - May state what the system should not do
 - Depends on SW type, expected users & type of system where the SW is used
 - Functional user req.s: May be high-level statements of what the system should do
 - Functional system req.s: describes system services in detail

- **Non-functional requirements:** Constraints on system services or func.s
 - Timing constraints, development process constraints, standards, etc.
 - Often apply to the system as a whole, rather than individual features
 - May be more critical than functional requirements
 - May be difficult to state precisely, which may be difficult to verify
 - "Goals" (general intentions of the user) can be specified instead
 - A "verifiable nonfunc. req." uses some measure that can be tested objectively
 - Speed: operation time, response time, refresh rate etc.
 - Size
 - Ease of use
 - Reliability: Failure rate, availability etc.
 - Robustness: Recovery from failure
 - Portability: Target-dependent statement rate
 - A single nonfunc. requirements may generate several related
 - Product requirements: execution speed, reliability etc.
 - Organizational requirements: Consequence of organizational policies & procedures (e.g standards, implementation requirements etc.)
 - External requirements: interoperability requirements, legal requirements etc.
 - **Domain requirements:** System constraints from the operation domain
-

- In principle: Requirements should be complete & consistent:
 - Completeness: include descriptions of all required system facilities
 - Consistency: No conflicts in the descriptions of the system facilities
 - Complexity of environment & system -> impossible to produce a complete and consistent requirements document

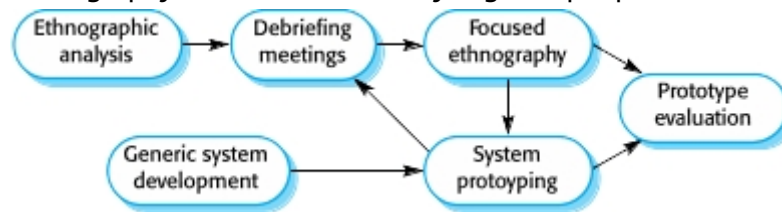
Requirements Engineering Process

- An iterative activity in which req. elicitation, analysis, validation and management are interleaved

Req.s Elicitation / Discovery

- Technical staff works with stakeholders to find out about application domain, system services & system's operational constraints
- Stages (in a cycle):
 - Req.s discovery
 - Getting info. from stakeholders about the required & existing systems
 - Interviewing:
 - closed (pre-determined questions) or open, or mixed
 - Not good for understanding domain requirements: Stakeholder can unintentionally overlook them since they are already familiar with the domain

- Ethnography: Social scientist analyzing how people work



- Important social & organizational factors can be observed
- Effective for understanding existing processes
- Cannot identify new features to be added to a system
- Specifying user & system requirements from the gathered info.
 - Req.s classification & organization
 - Req.s prioritization & negotiation
 - Conflicts are resolved here
 - Req.s specification
 - Req.s are documented here
- Problems:
 - Stakeholders may have unstable decisions
 - Stakeholders express req.s in their own terms
 - Stakeholders' req.s may conflict
 - Organizational & political factors may influence the req.s
 - Stakeholders & business environment may change -> Req.s change during analysis process
- User stories: Real-life system usage examples
 - Practical situation -> stakeholders can relate and comment
- Scenarios: Structured form of user stories
 - Should include starting situation, normal event flow, what can go wrong, state when scenario finishes, other concurrent activities

Requirements specification

- Process of documenting the req.s
- Requirements are written using natural language + diagrams & tables
- Problems with NL:
 - Lack of clarity: Hard to be precise without being complex
 - Functional & nonfunc. req.s may get mixed up
 - Several req.s can be expressed together
- Form-based specifications: Definition of function/entity, description of inputs, outputs, computations, pre & post conditions, any side effects of the function
- Tabular specification: Supplements NL
 - Useful when there are alternative courses of action

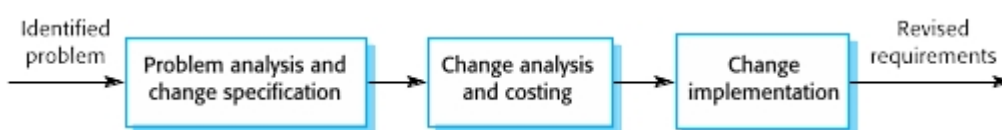
- Use-cases: Identifies an interaction and involved actors
 - A set of use-cases should describe all possible interactions with the system
- SW Req. document should describe "what" the system should do rather than "how" it should do
- Incremental development -> Less detail in req.s document

Requirements Validation

- Validating that the requirements define the system that the customer really wants
- Important: Errors in req.s are costly
- Check:
 - Validity (whether system provides func.s tht best supports customer's needs)
 - Consistency
 - Completeness
 - Realism (whether implementation with given budget & tech is possible)
 - Verifiability (whether the req.s can be tested)
- Techniques:
 - Reviews (systematic manual analyses)
 - Both client and contractors should be involved
 - Formal or informal
 - Check: Verifiability, comprehensibility, traceability (whether origin of the req. is clear), adaptability (whether the req. can be changed without large impact on other req.s)
 - Prototyping
 - Test-case generation

Requirements Management

- Managing changing req.s during req. engineering and system development
 - New req.s emerge as system is being developed and after is deployed
- Req.s mng. planning:
 - Req.s identification: Needed so that a req. can be cross-referenced with other req.s
 - Change management process: Set of activities to assess impact & cost of changes
 - Traceability policies: Define relationships between req.s
 - Tool support



CH5 - System Modeling

- Representing system using a graphical notation - almost always based on UML
- Models of existing systems are used during req. eng. to clarify its purpose & as a basis for strengths and weaknesses -> Lead to req.s for new system
- Models of new systems are used during req. eng. to explain req.s to other stakeholders
 - Engineers use it to discuss design proposals & document system for implementation
- Model driven engineering: Possible to implement system (partially or completely) from model

System Perspectives

- External perspective: Model context or environment
- Interaction perspective: Model interactions between system & environment or between system components
- Structural perspective: Model organization of system or the structure of processed data
- Behavioral perspective: Model how the system responds to events

UML Diagram Types

- Activity diagrams
- Use-case diagrams: Shows system - environment interactions
- Sequence diagrams: Shows actor - system interactions and interactions between system components
- Class diagrams: Shows object classes and the associations inbetween
- State diagrams: Shows the system's reactions to internal & external events

Context Models

- Shows system's operational context & boundaries
 - Social and organizational concerns affects the boundary
 - Boundary position profoundly affects system req.s
 - Simply shows other systems in the environment, not how it is used or developed
 - Process models show how they are used
 - UML Activity diagrams may be used to define process models
- Architectural model: Shows relationship among systems

Interaction Models

- Use-case and sequence diagrams may be used to model inter-system and inter-component interactions

Use-case Diagrams

- Each use case represents a discrete task that involves external interaction with a system
 - Actors in a use case may be people or other systems

- Represented as a diagram for overview and also in a more detailed textual form

Sequence Diagrams

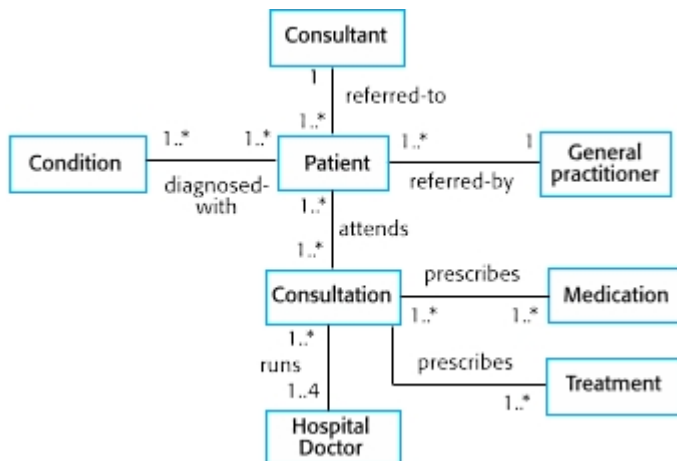
- Part of UML showing sequence of interactions taking place during a particular use-case

Structural Models

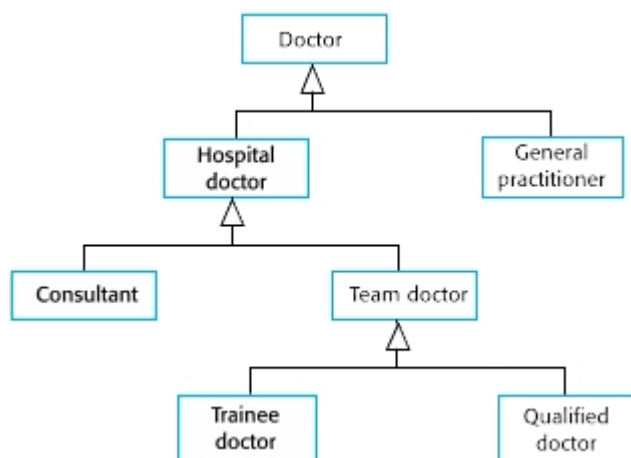
- Display system organization in terms of its components and their relationships
- Static models: show structure of system design, dynamic models: show system organization during execution
- Created when system architecture is being created & discussed

Class Diagrams

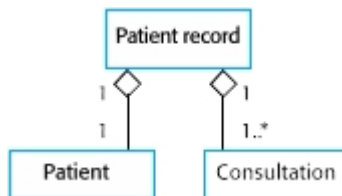
- Object Class: General definitiob of one kind of system obejct
 - During early stages of SW engineering: objects represent an entity in the real world



- Generalization: Base class - Derived class relation

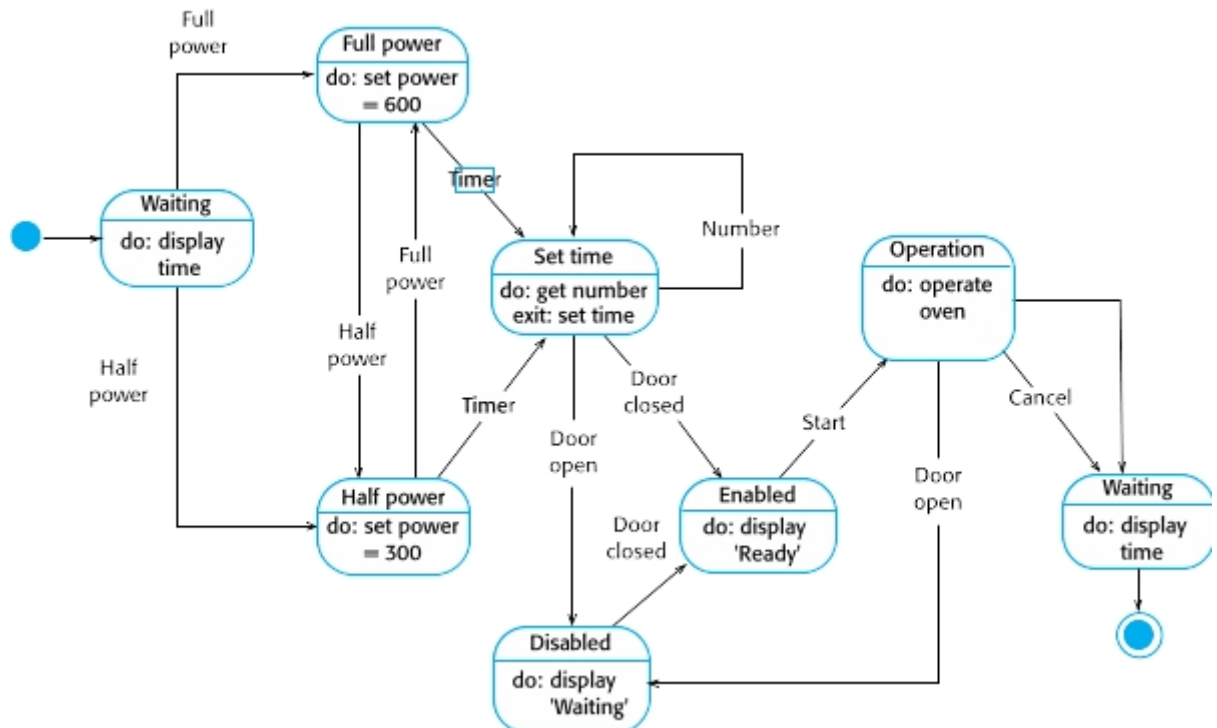


- Aggregation association: Class is composed of other classes
 - Subclasses do not depend on aggregating class to be able to exist - similar to an "array - array element" relation



Behavioral models

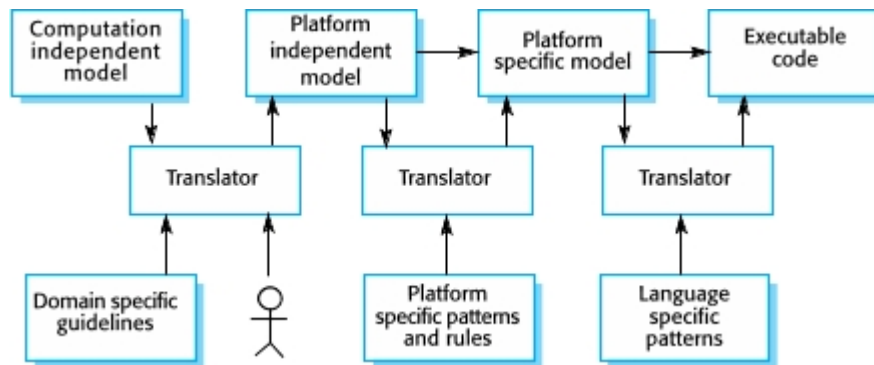
- Models a system's dynamic behavior during execution
 - Show expected response to environmental stimulus
- Types of environmental stimuli:
 - Data: input to be processed by system
 - Events: Trigger system processing
 - May or may not have associated data
- Data-driven models: Show sequence of actions in processing input & generating associated output
 - Most business systems are data-driven, minimal external event processing
 - Shows end-to-end processing in a system -> Useful in req.s analysis
- Event-driven models: Shows system's response to external & internal events
 - Most real-time systems are event-driven, minimal data processing
 - Based on assumption that a system has finite states & events/stimuli cause transition between states
 - State machine models: Show system's responses to internal & external events



- Statechart in UML are used to represent state machine models

Model-Driven engineering

- Principal outputs of development are models rather than programs
 - Programs are later generated from models
 - Increases abstraction: Engineers no longer have to be concerned with details related to programming languages or execution platforms
 - Method is still in developments
 - Cheaper code generation but developing translators for new platforms may be expensive
- Model-driven architecture (MDA): Model a system using a subset of UML modules, at different levels of abstraction, generate implementation from model. In principle, it is possible to generate a working program without manual intervention.
 - Computation-independent model (CIM) / Domain model: Model important domain abstractions in a system
 - Platform-independent model (PIM): Model operation without referencing implementation
 - Usually described using UML to show response to stimuli & static system structure
 - Platform-specific model (PSM): Transformation of PIMs for specific platforms
 - Can be layered according to added details



- Iterative approach of MDA suggests agile, however up-front modeling contradicts.
 - Can be used in agile if PIM-to-program transformation can be fully automated
- MDA has limited adoption:
 - Limited tool availability for model conversion between abstraction levels
 - The abstractions that are useful for discussions may not be the right abstractions for implementation
 - For most complex systems, req. eng, security, dependability, backwards compatibility, testing etc. are more significant problems than implementation
 - Prevalance of agile has diverted attention away from MDA

CH6 - Architectural Design

- Concerned with overall structure & organization of a SW system
 - Results with an "architectural model" identifying relation between system components -> Critical link between design and req.s engineerings
 - Early stage of agile processes

- Refactoring architecture affects many system components -> expensive
- Architectural abstraction:
 - Small scale: arch. of individual programs & its components
 - Large scale: arch. of large systems involving other systems & programs
- Explicit architecture benefits:
 - Used for discussion & communication with stakeholders
 - Analyzing system for whether it can meet its nonfunc. requirements
 - An architecture can be reused for other systems
- Box & line diagram representations of architecture: Very abstract but good for communication with stakeholders

Architecture and system characteristics

- Performance: Localize critical operations, minimize communications, use "larger" components
- Security: Use layered architecture with critical assets in the inner layers
- Safety: Localise safety-critical features in a small number of sub-systems.
- Availability: Include redundant components and mechanisms for fault tolerance.
- Maintainability: Use replaceable components

Architectural views

- Relate different views using use-cases & scenarios:
 - Logical view: Show key abstractions in the system as objects & object classes
 - Process view: Show how the system is composed of interacting processes at run-time
 - Development view: Show how the SW is decomposed for development
 - Physical view: Show how HW & SW components are distributed across processors in system
- Represent views with UML or architectural description lang.s (ADLs)

Architectural patterns

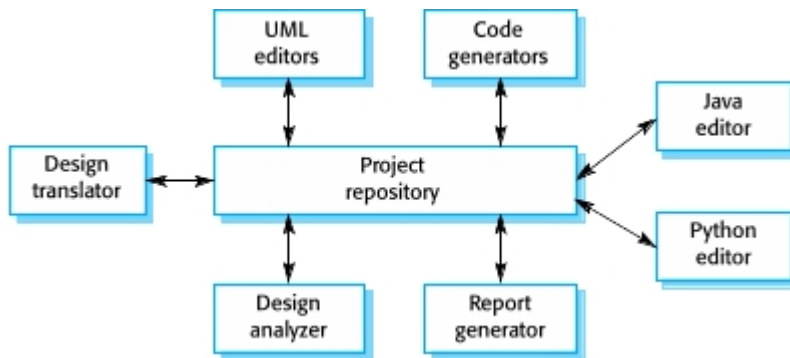
- Patterns: means of representing, sharing, reusing knowledge
 - architectural pattern: stylized description of good design practice, which has been tried and tested in different environments
 - Should include info. about when they are useful and when they are not
 - May be represented using tabular & graphical descriptions

Layered architecture

- Used to model sub-systems interface

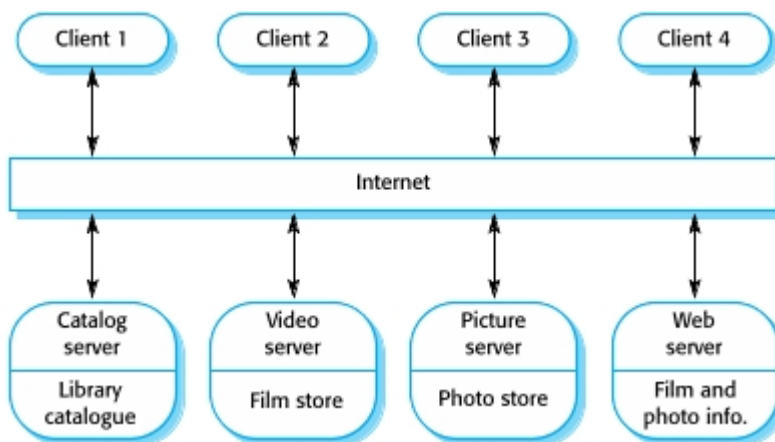
- Organizes system into a set of "abstract machine" layers
 - Each provides a set of services
- Supports incremental development
 - A layer changes -> only adjacent layers affected
- Example: layers from OS to the user interface

Repository architecture



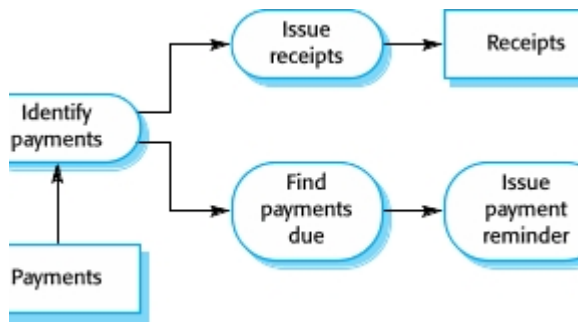
- Efficient data sharing mechanism when large amounts of data is shared among subsystems
 - Shared data held in central database instead of each subsystem maintaining their own databases

Client-server architecture



- Distributed system model which shows how data and processing is distributed across a range of components
 - Can be implemented on a single computer
 - Set of stand-alone "servers" providing specific services, "clients" calling these services & "network" providing clients access to the servers

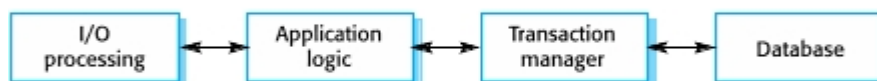
Pipe & Filter architecture



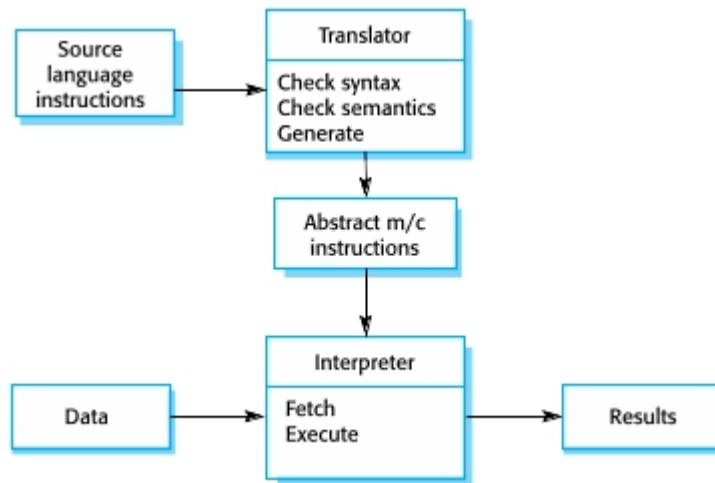
- Input -> functional transformations -> output
- If transformations are sequential: "batch sequential model", used extensively in data processing systems
- Not very suitable for interactive systems

Application architectures

- Architecture for a type of system that may be configured and adapted to fulfill specific requirements.
- Used as:
 - A starting point for architectural design.
 - A design checklist.
 - Way of organising the work of the development team.
 - Means of assessing components for reuse.
 - To discuss application types.
- Two widely used generic app. architectures:
 - Transaction processing systems

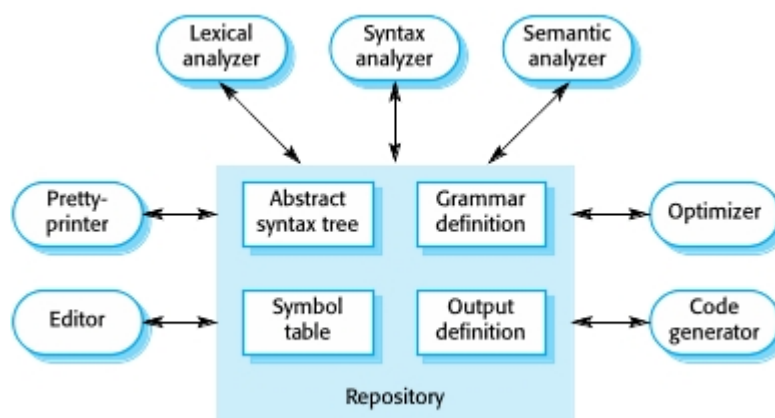


- Data centered app.s proccessing user requests & updating info in a system database
- Users make asynchronous requests for service which are then processed by a transaction manager
- E-commerce sys.s, reservation sys.s, etc.
- Language processing systems

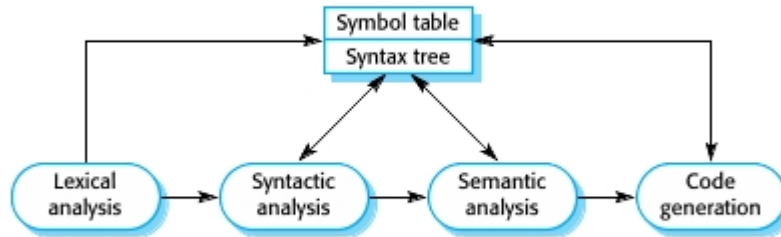


- App.s where user specifies intentions in a formal language, which is processed & interpreted by the system
- Compilers, command interpreters etc.
- Compiler components:
 - Lexical analyzer: Converts language tokens to internal form
 - Symbol table: holds info. about names of entities used in text
 - Syntax analyzer
 - Syntax tree: internal structure of the program being compiled
 - Semantic analyzer: Uses info. from syntax tree & symbol table to check semantic correctness of text
 - Code generator: "Walk" syntax tree to generate abstract machine code

Repository compiler architecture:



Pipe & filter compiler architecture:



Information systems architecture

- Can be organized in layers
 - Layers: UI, User communications, info. retrieval, system database...
 - Transaction-based since interaction with these systems generally involves database transactions

CH7 - Design & Implementation

- Implementation: Realizing the design as a program
- Developing a modifiable "off the shelf system": design process is concerned with the configuration features

Object-Oriented Design With UML

- Involve developing a number of different system models - may not be cost-effective for small systems
- Common activities include:

1) Defining system context & interactions

- Defines relationship between software and external environment
- Establishes system boundaries - helps decide which features to implement
- **System context model:** Demonstrates other systems
- **Interaction model:** e.g. Use case model & descriptions

2) Designing system architecture

- Organize components in an architectural pattern (e.g. layered, client-server...)

3) Identifying object classes

- Relatively difficult & an iterative process
 - Considering tangible entities & scenerio based analysis (as in use case model) helps

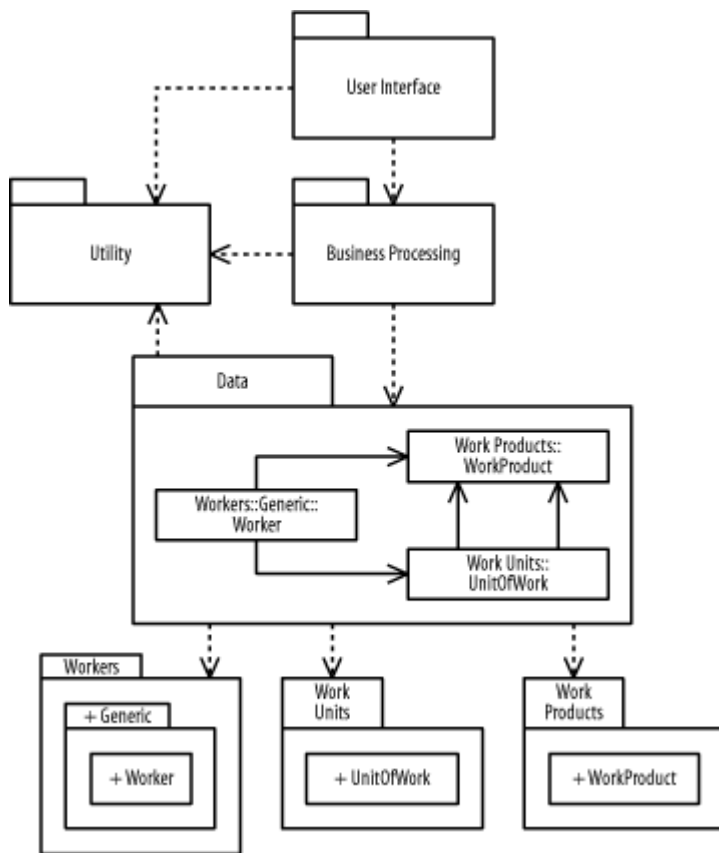
- In the system's verbal description: Generally objects & attributes correspond to nouns, operations & services correspond to verbs

4) Developing design models

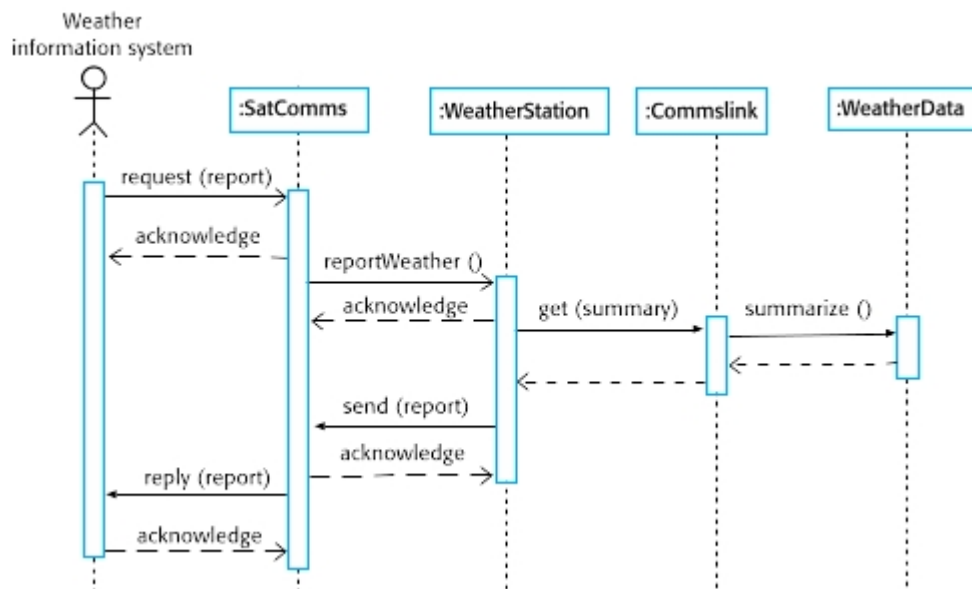
- **Design model:** Shows relations between objects/object classes
 - **Structural model:** Describes static structure of object classes & relationships
 - **Dynamic model:** Describes dynamic interactions between objects

Examples:

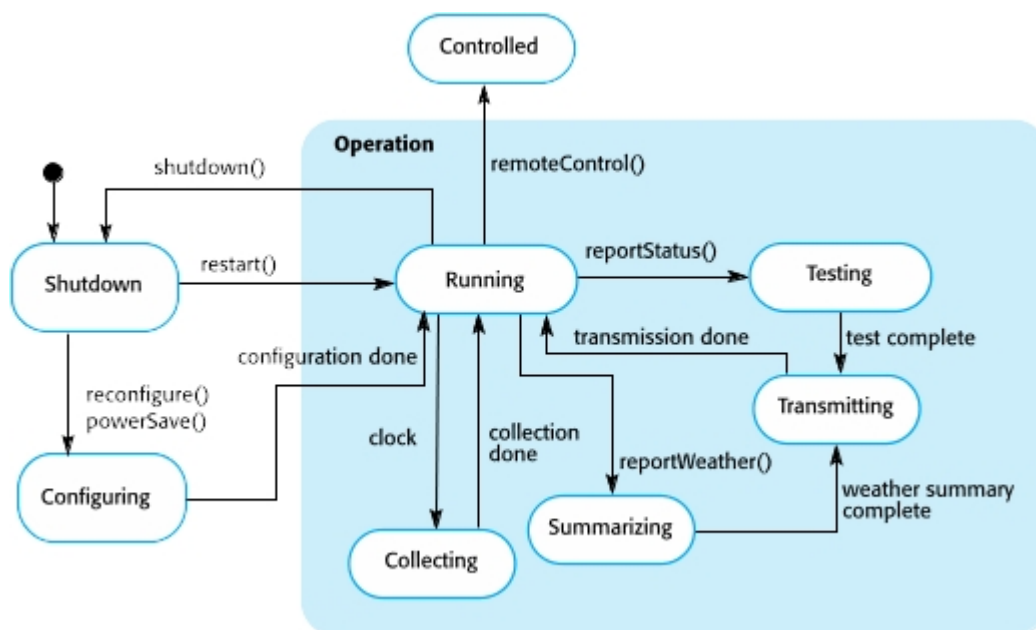
- **Subsystem models:** Show logically related groups of objects
 - Shown with "packages" in UML



- **Sequence models:** Show sequence of object interactions



- **State diagrams:** Show objects' response to service requests & triggered state transitions
 - Useful for modeling run-time behavior
 - Not needed / Unnecessarily complex for most objects



5) Specifying object interfaces

...