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
  - **Dependablity:** Security, reliability, safety. Should not cause damage in case of failure
  - **Efficiency**
  - **Acceptability:** Compatible with other systems, understandable, usable

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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-oriened 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 alll involve: Specification, design & implementation, validation, evolution

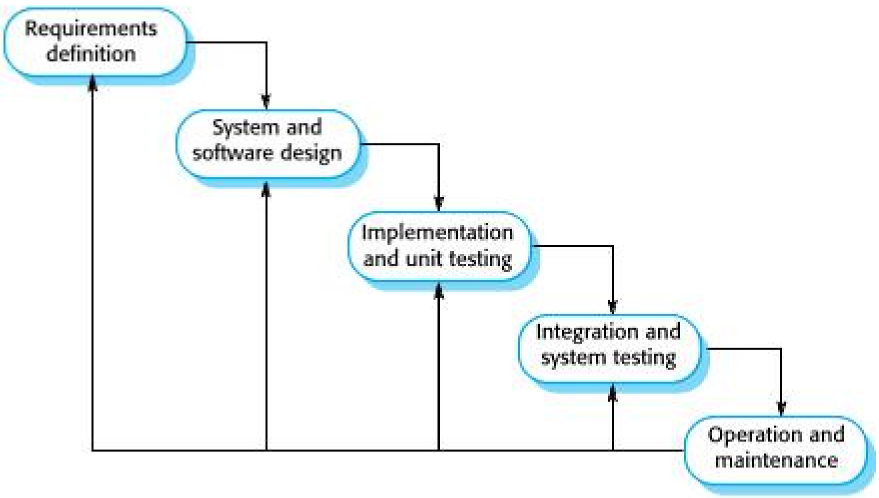
- "Plan driven process": all activities planned in advance, progress is measured against the plan

"Agile process": Incremental planning, easier to change provess to changing requirements

Often, elements from both approaches are used.

Software Process Models

The Waterfall Model

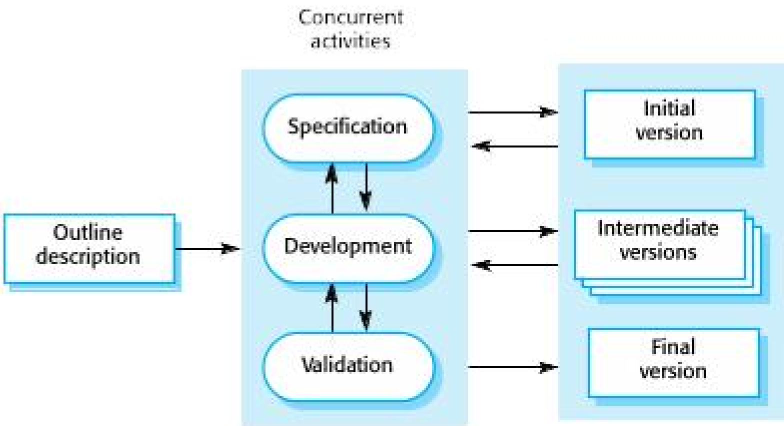


- Plan-driven

- Separate identified phases

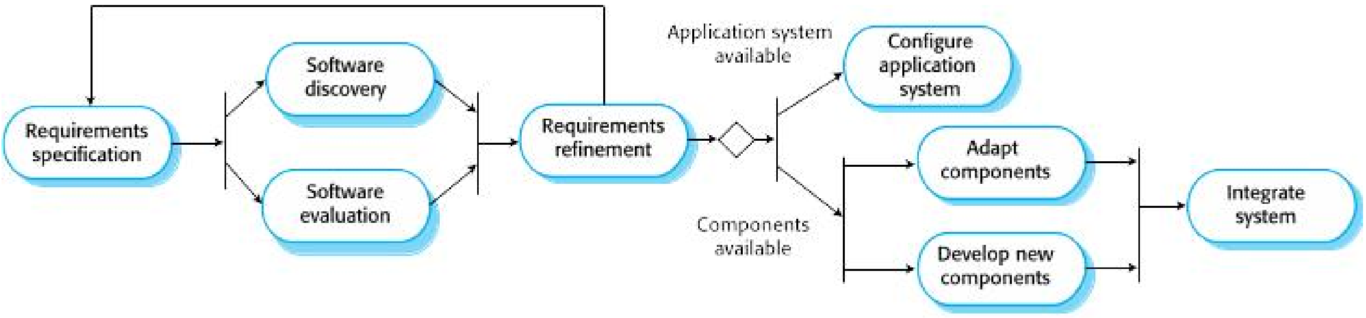
- Drawback: a phase has to be completed before moving onto next, hard to accomodate changes
    - Only appropriate when the requirements are well understood & changes will be limited
- Mostly used for large system engineering projects where a system is developed at several sites

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.)



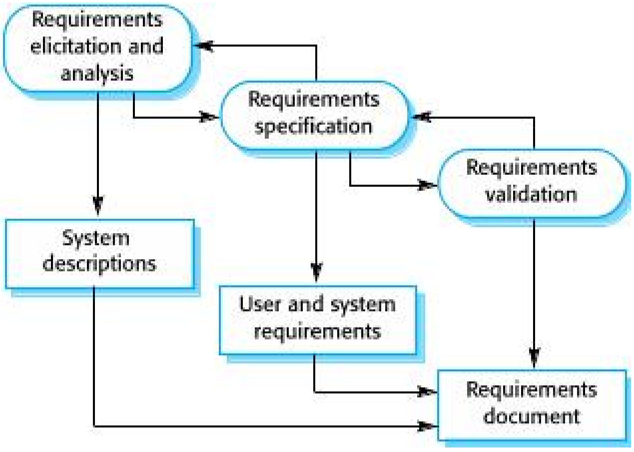
- Based on software reuse - reused elements can be configured according to requirements
- Standard approach for many business system types

- 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

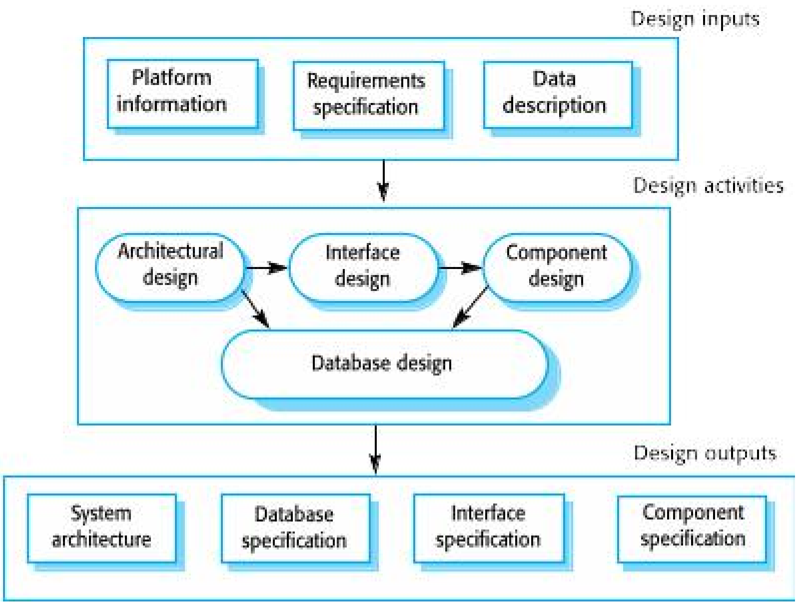
Process Activities

- Can be ordered sequentially or interleaved according to the model

Requirements Engineering Process



Software Design & Implementation

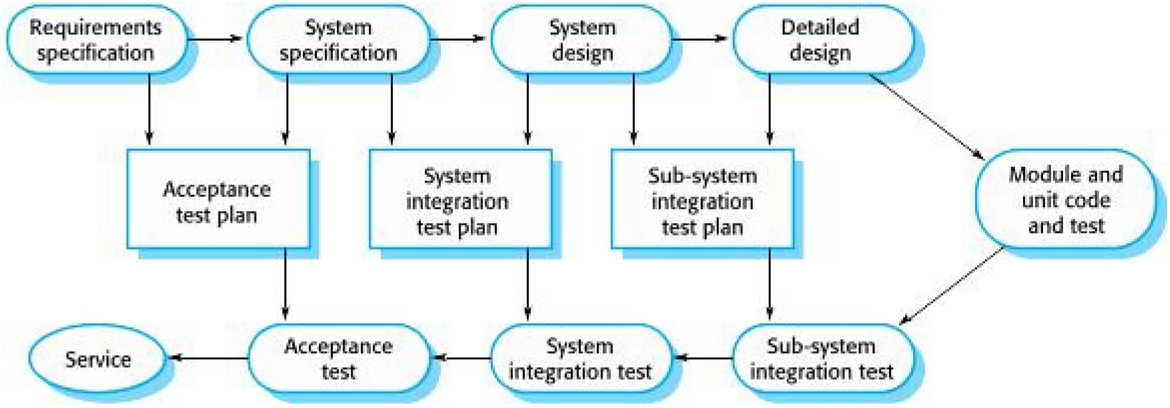


- Design: Creating software structure
    - Architectural, database, interface (between components), component selection & design
- Implementation: translating the structure into an executable
    - Design & implementation can be closely related or interleaved

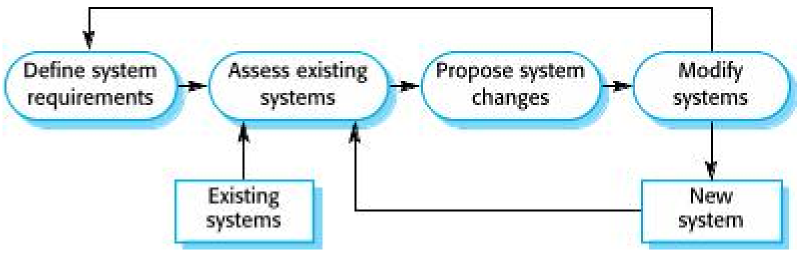
Software Validation

- Testing: Most common verification & validation activity

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

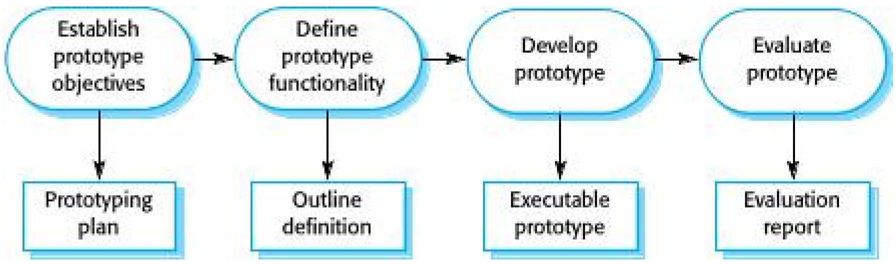


System Evolution



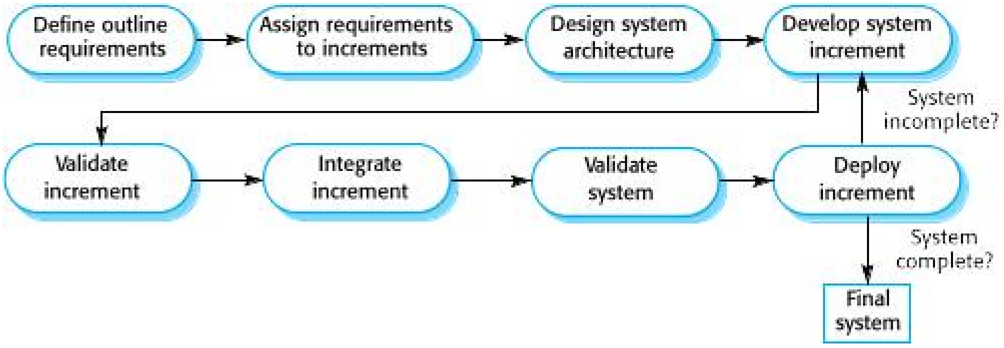
- Change anticipation: Possible changes can be anticipated without much rework
- Change tolerance: Process is designed so that changes are applied without much cost

Software Prototyping



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

Incremental Development & Delivery

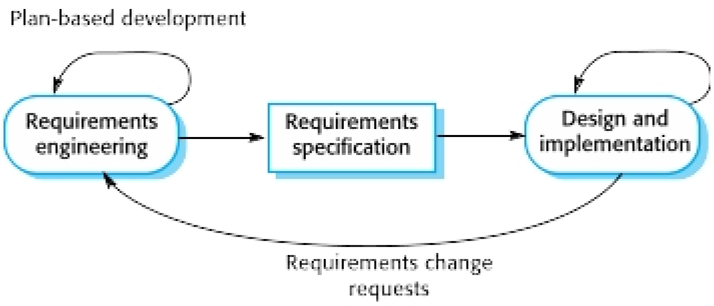


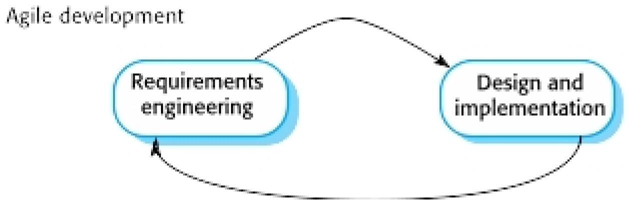
- Early increments serve as prototypes
- Requirements are not changed throughout the development of an increment
- Highest priority services receive most testing
- Specification is developed toghether with the SW itself
  - May contradict procurement models of some organizations

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





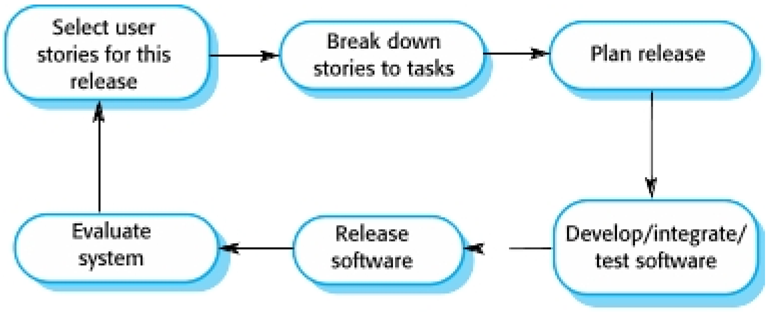
- Program specification, design and implementation are inter-leaved
- The system is developed as a series of versions or increments with stakeholders involved in version specification and evaluation
- Frequent delivery of new versions for evaluation
- Extensive tool support (e.g. automated testing tools) used to support development.
- The aim is to reduce overheads in the SW process, to be able do 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 prescripted processes
- Embrace change
- Maintain simplicity

Agile development techniques

Extreme programming (XP)

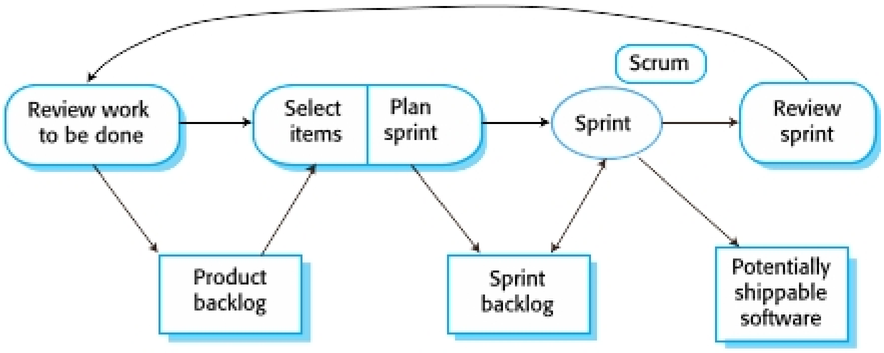


- "Extreme" iterative development:
    - New versions may be built several times per day
    - Increments are delivered to customers every 2 weeks
    - All tests must be run for every build and the build is only accepted if tests run successfully.
- Has a technical focus - usually not easy to integrate 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 managable 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 approporiate for new software rather than maintenance
  - In large companies usually: Maintenance cost > development cost
- Agile is more approporiate 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

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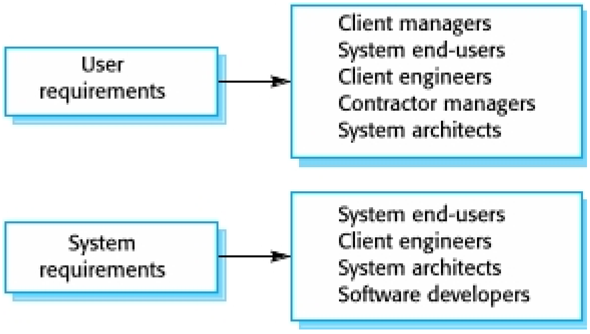
- Several integrated systems: Significant amount of development on system configuration rather than development
- Completely incremental approach to requirements engineering is impossible
- Continuous integration practically impossible. However, frequent system builds & regular releases are essential
- 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: Desctiptions 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 individiual 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

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- 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

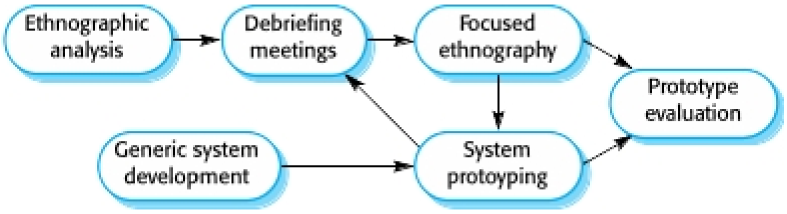
Requirements Engineering Process

- An iterative activity in which req. elicititaion, 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

            - 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

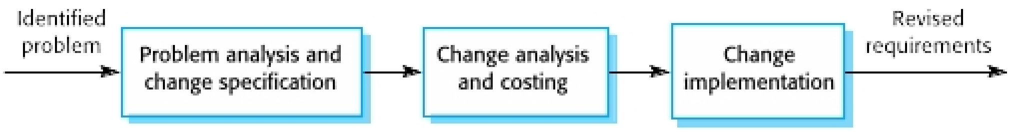
- Use-cases: Identifies an interaction and involved actors
    - A set of use-cases should describe all possible interactions with the system
- SW Req. document should describe "what" the system should do rather than "how" it should do
- Incremental development -> Less detail in req.s document

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 wtihout 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 impacr & cost of changes
    - Traceability policies: Define relationships between req.s
    - Tool support



CH5 - System Modeling

- Representing system using a graphial 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 perpective: 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

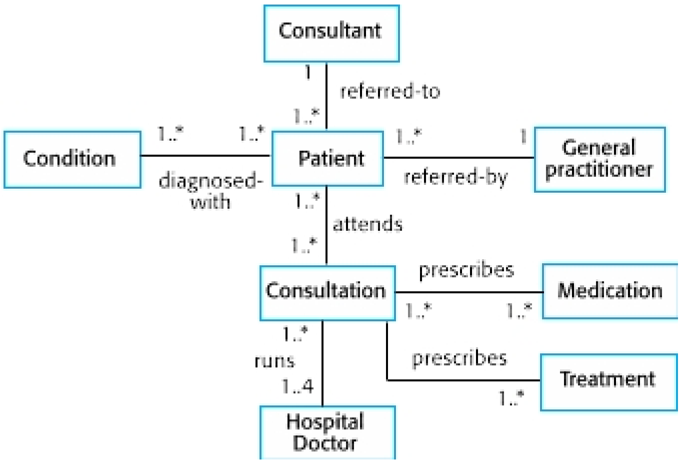
- Part of UML showing sequence of interactions taking place during a particular use-case

Structural Models

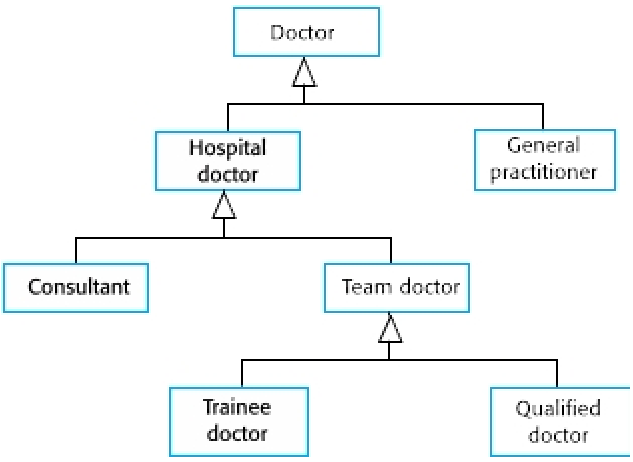
- Display system organization in terms of its components and their relationships
- Static models: show structure of system design, dynamic models: show system organization during execution
- Created when system architecture is being created & discussed

Class Diagrams

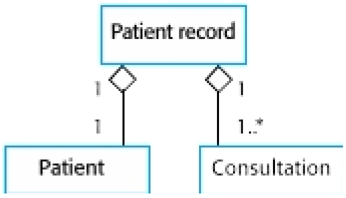
- Object Class: General definitiob of one kind of system obejct
  - During early stages of SW engineering: objects represent an entity in the real world



- Generalization: Base class - Derived class relation

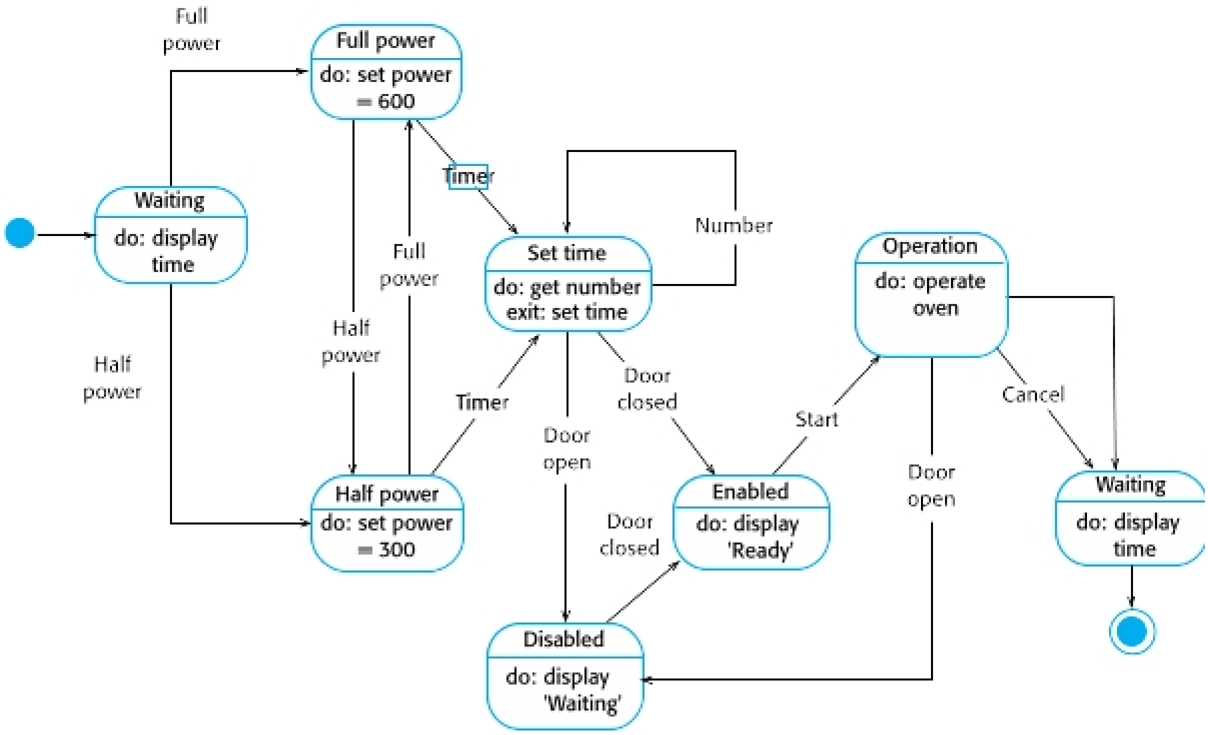


- Aggregation association: Class is composed of other classes
  - Subclasses do not depend on aggregating class to be able to exist - similar to an "array - array element" relation



Behavioral models

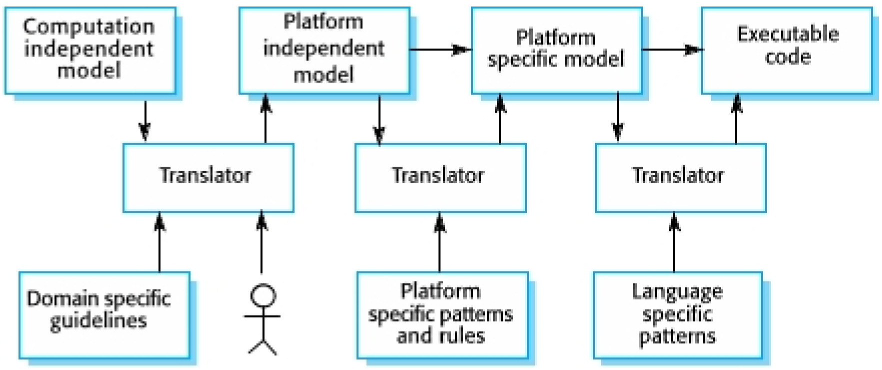
- Models a system's dynamic behavior during execution
  - Show expected response to environmental stimulus
- Types of environmental stimuli:
  - Data: input to be processed by system
  - Events: Trigger system processing
    - May or may not have associated data
- Data-driven models: Show sequence of actions in processing input & generating associated output
  - Most busines 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