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Human Centred Systems Design

Software Engineering and Human-Computer Interaction
Understanding Requirements and Evaluating Solutions

Part 1: Introduction to Software Engineering

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(thanks to Dr Anthony Simons and Dr Amanda Sharkey for providing the original slides)

Lecturers, Lectures and Assessment

Tony Simons

Software Engineering & Databases

Thursdays

1 group project
60%

Heidi Christensen

Human-Computer Interaction

Tuesdays

Set of questions
20%

Maria-Cruz Villa-Uriol

Human-Computer Interaction

Tuesdays

Set of questions
20%

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Bibliography

Software Engineering

- I Sommerville, Software Engineering, 8th ed., Addison-Wesley, 2007.

- R S Pressman, Software Engineering: A Practitioner's Approach, 6th ed., McGraw-Hill, 2005.

Overview

- Software Engineering vs Computer Science

- Software Engineering Life cycle

- Process management

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CS and SE: What's the difference?

- **Computer Science**
  - develops theory, methods, limits of what is computable
  - algorithms, data structures, formal grammars, abstract machines, numerical analysis

- **Software Engineering**
  - applies theory, methods to solve practical problems
  - creates complex software products
  - follows a design, management process
  - uses models of systems (diagrams, specifications)
  - deals with people (stakeholders, managers)

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Software Engineering…

- is the application of a systematic, disciplined, quantifiable approach to the development, operation and maintenance of software.

  [IEEE Standard Glossary of Software Engineering Terminology, IEEE std 610.12, 1990]

- is an engineering discipline that is concerned with all aspects of software production.

  [I Sommerville, p7]

- is the establishment and use of sound engineering principles in order to economically obtain software that is reliable and works efficiently on real machines.

  [F L Bauer, NATO Conf. Softw. Eng., Garmisch, 1968]

Software Engineering

- NATO Conference, Garmisch, Germany, 1968
  - convened to discuss the “software crisis”
  - first coined the term “software engineering”

- The software crisis
  - delays in software delivery
  - higher costs than originally estimated
  - software unreliable, difficult to maintain

- Need for new methods
  - engineering discipline (apply theories within real constraints)
  - cover all aspects of production (technical and management)

Software is Everywhere

- Business information systems
  - Banking, finance, purchasing, office data systems
- Embedded systems
  - Internet, telecoms, medical, industrial processes
- Lifestyle/entertainment
  - TV, video, film, games, publishing, social networks
- Science and engineering
  - Genetics, robotics, education, military ...
- Software is...
  - the most complex of any engineered human artifact

Kinds of Software

- System software
- Real-time software
- Business software
- Engineering and scientific software
- Embedded software
- Personal computer software
- Web-based software
- Artificial Intelligence software
- Research software

- Problems with software
  - Need for careful elicitation of requirements
  - Need for careful evaluation

Software Myths

- Management myths
  - Follow published standards for building software
  - Use state of the art tools to build software
  - Add more programmers if behind schedule
- Customer myths
  - General description of objectives is enough to start coding
  - Requirements may change as the software is flexible
- Practitioner myths
  - Task is accomplished when the program works
  - Quality assessment only when the program is running
  - Working program is the only project deliverable

Software Failures

- **Therac-25 (1985-1987)**:
  Six people overexposed during treatments for cancer
  - repeating radiation dose because machine's display said no dose had been given

- **UK Passport Office (2006)**:
  Project cancelled after 10 years, wasting £12m, wrecking 500 holidays; due to lack of testing and change control

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- UK’s National Public Health Software System

- The UK invested over £12 billion when they finally stopped all efforts on the software that was meant to link all the UK residents’ health record electronically.
- The project was started in 2002 and meandered on until 2011 when the plug was pulled citing that the software was outdated and didn’t fulfil the requirements. The project was severely over budget on time and money with no end in sight.

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39 seconds

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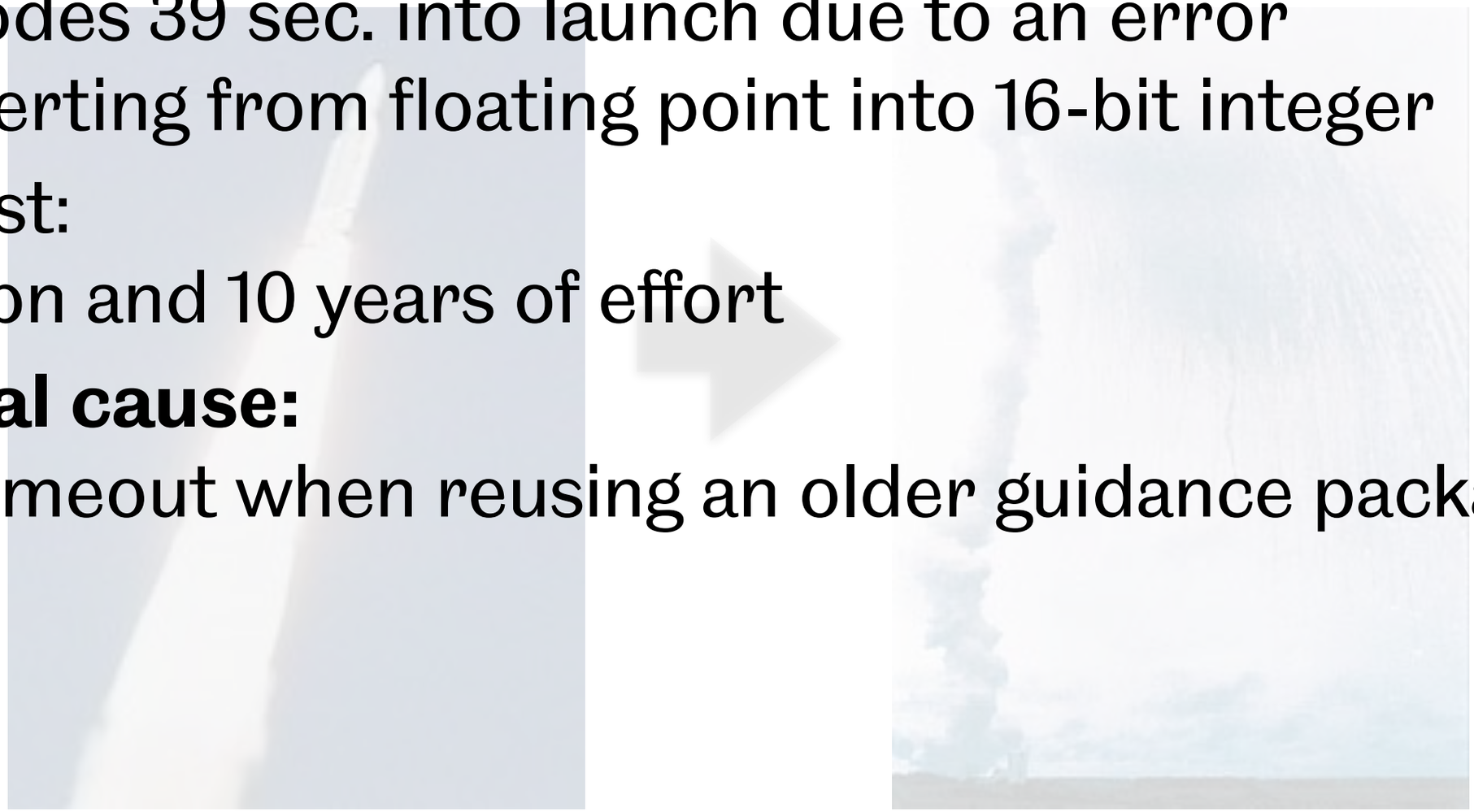
Technical Failures

- **Ariane 5 (1996):**
  explodes 39 sec. into launch due to an error converting from floating point into 16-bit integer
  - Cost:
    $7bn and 10 years of effort
  - **Real cause:**
    a timeout when reusing an older guidance package



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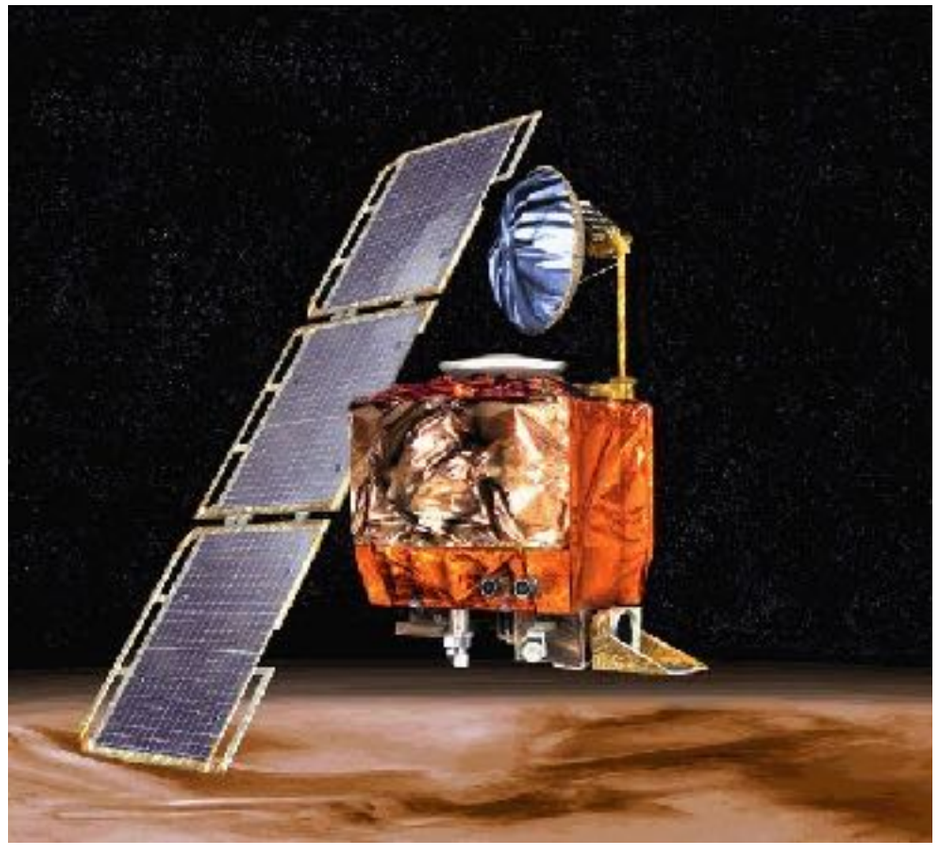
Systemic Failures

- **Mars Climate Orbiter (1999):** lost by NASA flight controllers during orbital insertion
  - Different measurement units (imperial and metric) for guidance and propulsion
  - **Real cause:** lack of communication between software teams



Ethical failures?

- **Volkswagen September 2015**

  - Emissions testing scandal

  - 482,000 VW diesel cars on US roads were emitting up to 40 times more toxic fumes than permitted

  - diesel cars were designed to cheat in tests

  - programme in engine software lets car perceive if it is being driven under test conditions

  - if it is, it reduces emissions

  - tested by an NGO, International Council on Clean Transportation conducted on road emission tests

  - Scandal may cost VW $35 billion in fines, lawsuits and other costs

Some Progress…

- Increased ability to produce more complex software systems (modular, component-based)
- Effective methods to specify, design, implement software have been developed (formal models, code generation)
- A better understanding of the activities involved in software development (people issues – psychology, politics)
- Novel software engineering approaches (clean room, time-boxed prototyping, test-first design)
- Standard notations and tools have been produced (UML, CASE tools)

Software Process

A software process consists of a *set of activities* and associated results which lead to the production of a software product [Sommerville, p 43]

Four fundamental activities:

- Software specification – requirements, formalisation
- Software development – design, implementation
- Software validation – validation, verification, testing
- Software evolution – bug fixes, upgrades, adaptation

Software involves: Products – Processes – Models – People

Software Lifecycle

- What kinds of activity?
- Commission a software system
  - Feasibility study
  - Requirements elicitation
- Construct the software system
  - Systems analysis, formal specification and design
  - Implementation, testing and deployment
- Maintain the software system
  - Fix faults, extend the system
  - Decommission the system

Lifecycle Activities – I

- Feasibility Study
  - Outline the objectives of the business
  - Met by the software system, or by other means?
- Requirements Elicitation
  - Collect required system behaviours from stakeholders
  - Use interviews, workshops; get different viewpoints
- Systems Analysis
  - Determine the scope, interface to other systems
  - Break down into models of: data, processing, time
  - Model what the system has to achieve (not how)

Lifecycle Activities – II

- Formal Specification
  - Logical model and proof of expected behaviour
  - For safety-, mission-, business-critical systems
- Systems Design
  - Split into units, modules and subsystems
  - Choose between alternative design strategies
  - Model how the system achieves its goals
- Implementation
  - Select technology: programming language, web script
  - Construct units, modules and integrate the system

Lifecycle Activities – III

- Testing
  - Unit testing, integration testing (up to specification)
  - Path coverage, stress-, load-testing (no failures)
  - Acceptance testing by users (up to requirements)
- Deployment
  - Install, configure system (at multiple sites?)
  - Operate the system
- Maintenance
  - Fix faults discovered late in the system
  - Add new functionality (new requirements)
  - Decommission the system (outlived its usefulness)

Software Process Models

- Traditional software process models
  - Waterfall software lifecycle model [Royce, 1970]
  - Spiral software lifecycle model [Boehm, 1988]
  - V-model of the software lifecycle [Germany, 1996]
- Formal software process models
  - Cleanroom [IBM]
  - VDM or Z/B with refinement
- Radical software process models
  - Prototyping models (rapid- ; evolutionary-)
  - Time-boxed models (Rapid Appl. Dev., DSDM)
  - Agile methods (eXtreme Programming, Scrum)

Mini-Lab: Which Lifecycle?

- Your client is a healthcare SME (small company)
  - they want a ground-breaking software system to learn the links between disabilities and the kinds of equipment prescribed by doctors.
- Your client is the Daimler AG automotive company
  - they want to coordinate the release of their on-board engine monitoring system with matching engine maintenance systems at garages.
- Your client is Boeing Commercial Airplanes
  - they want the latest fly-by-wire and on-board entertainment systems for the next-generation Dreamliner airplane.
- Your client is the UK National Health Service
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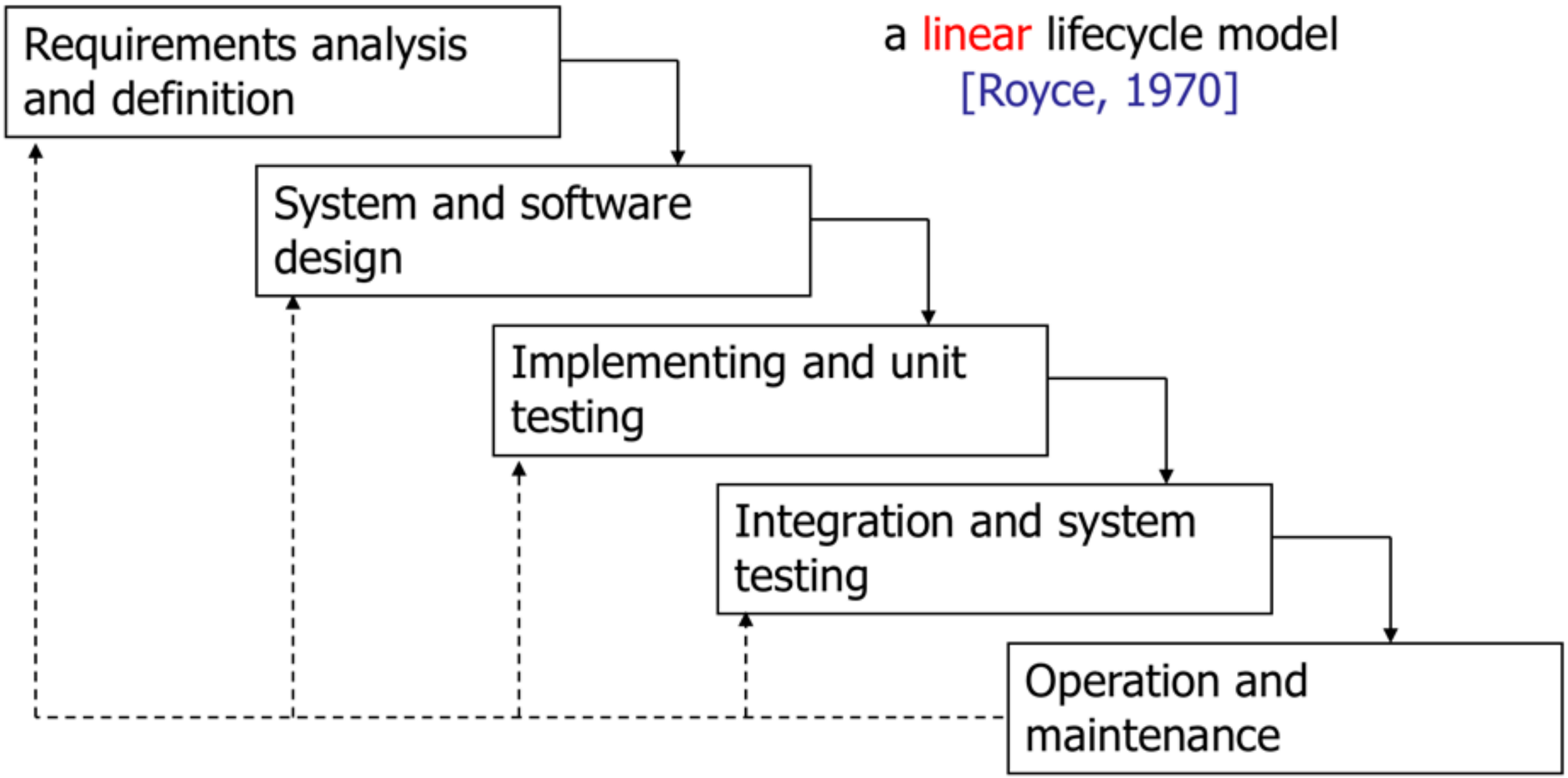
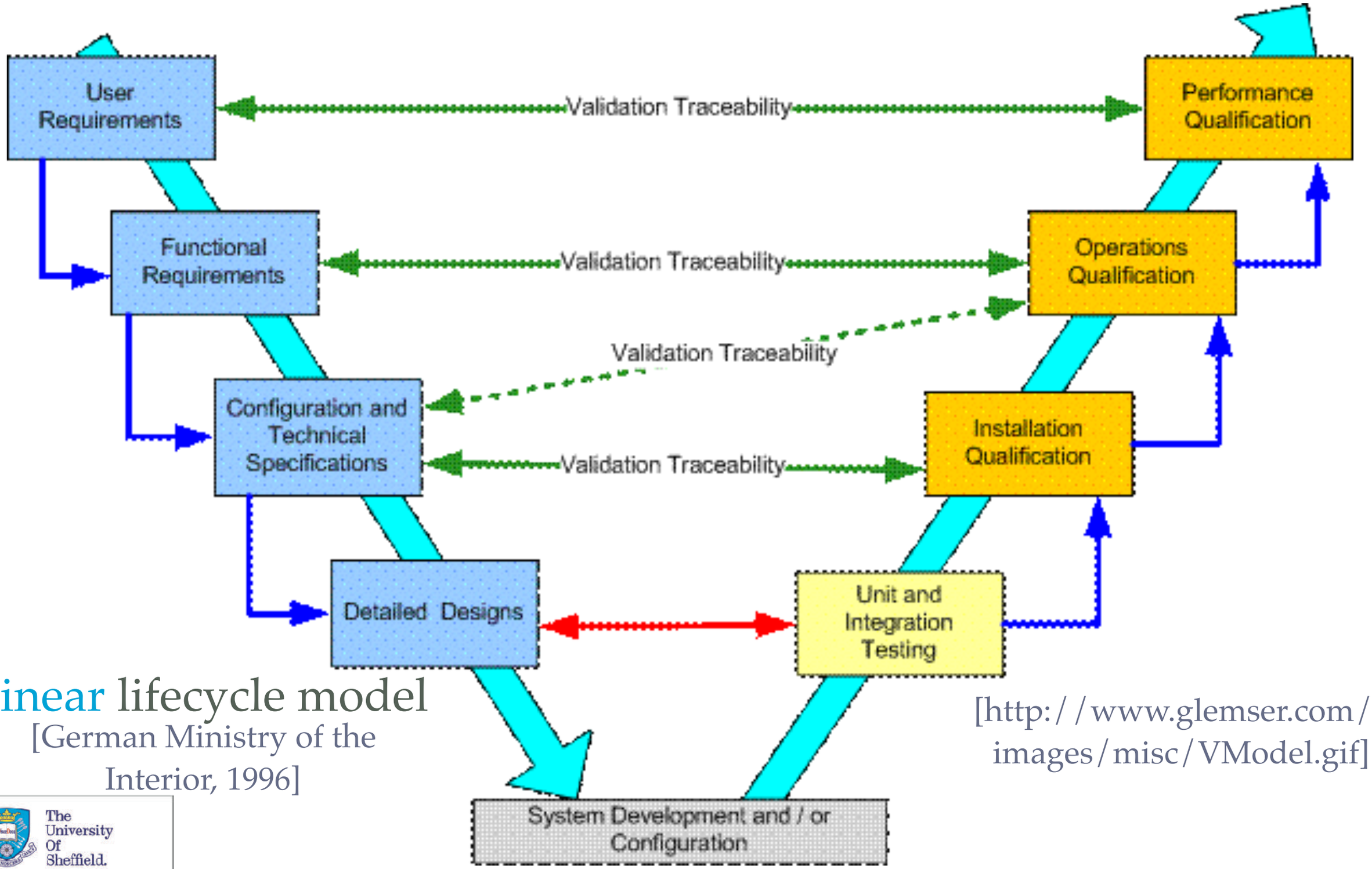
Waterfall Lifecycle Model



a linear lifecycle model
[Royce, 1970]

German V-Model



a linear lifecycle model

[German Ministry of the Interior, 1996]

[http://www.glemser.com/images/misc/VModel.gif]

Waterfall: Evaluation

- Strong points
  - staged development reflects engineering practice
  - encourages a discipline of abstract modelling, to break down complex systems into parts, views
  - good for project management, coordination, documentation
  - V-model matches each specification stage with a validation stage, reducing cost of faults discovered early
- Weak points
  - linear process is inflexible – in practice, stages overlap
  - imposes early commitment to rigid requirements
  - working version of programs only available late in the project time span
  - difficult to deal with late changes – increasing costs
  - real systems evolve faster than one complete cycle

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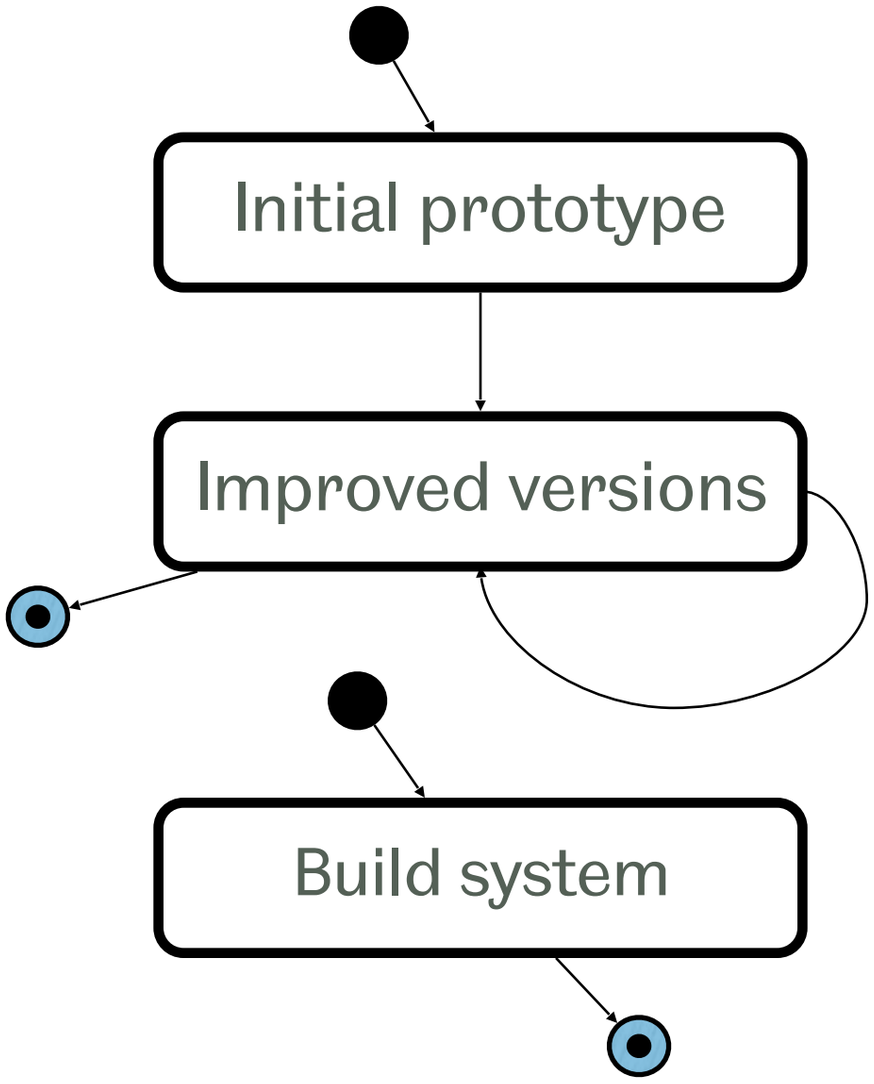
Rapid Prototyping

- Reasons to adopt
  - Requirements are vague or poorly understood
  - Build a prototype to help elicit requirements
  - Collect feedback
- Software lifecycle
  - Build a basic prototype
  - Iterate the prototype, add or change features
  - When acceptable, **discard** and build finished system

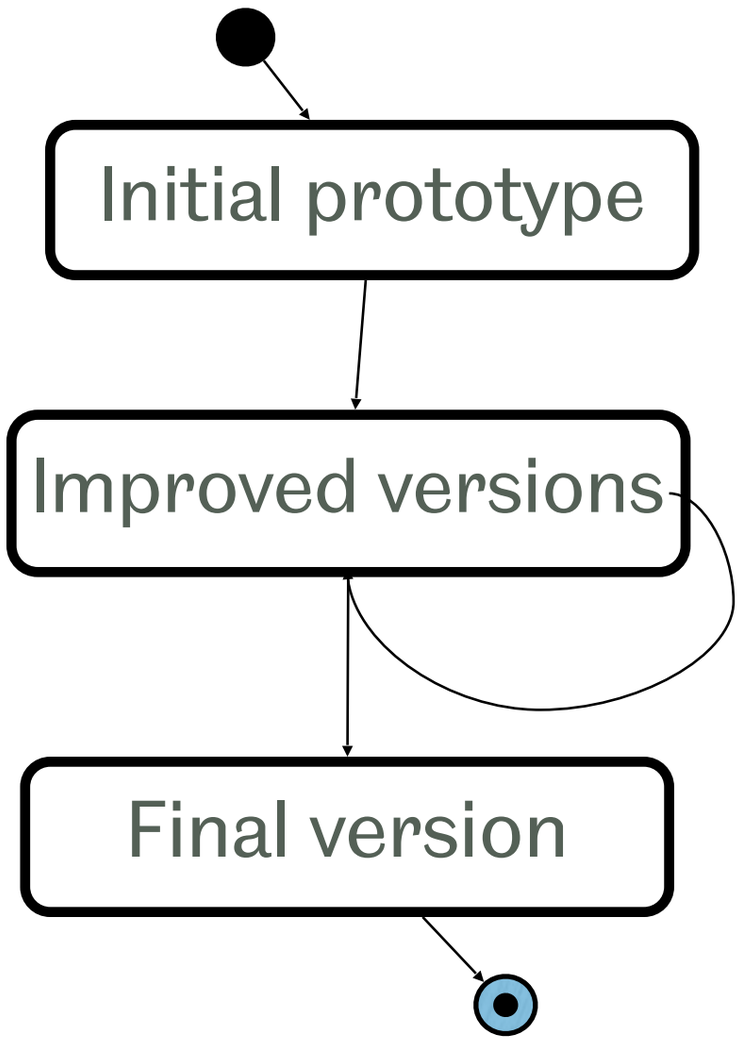
an iterative lifecycle model



Evolutionary Prototyping

- Reasons to adopt
  - Requirements are vague or misunderstood
  - Time constraints may force early termination
- Software lifecycle
  - Build a basic prototype
  - **Evolve** the prototype towards finished system
  - Stop when the system is ready, or the time limit is exceeded

an iterative lifecycle model



Prototyping: Evaluation

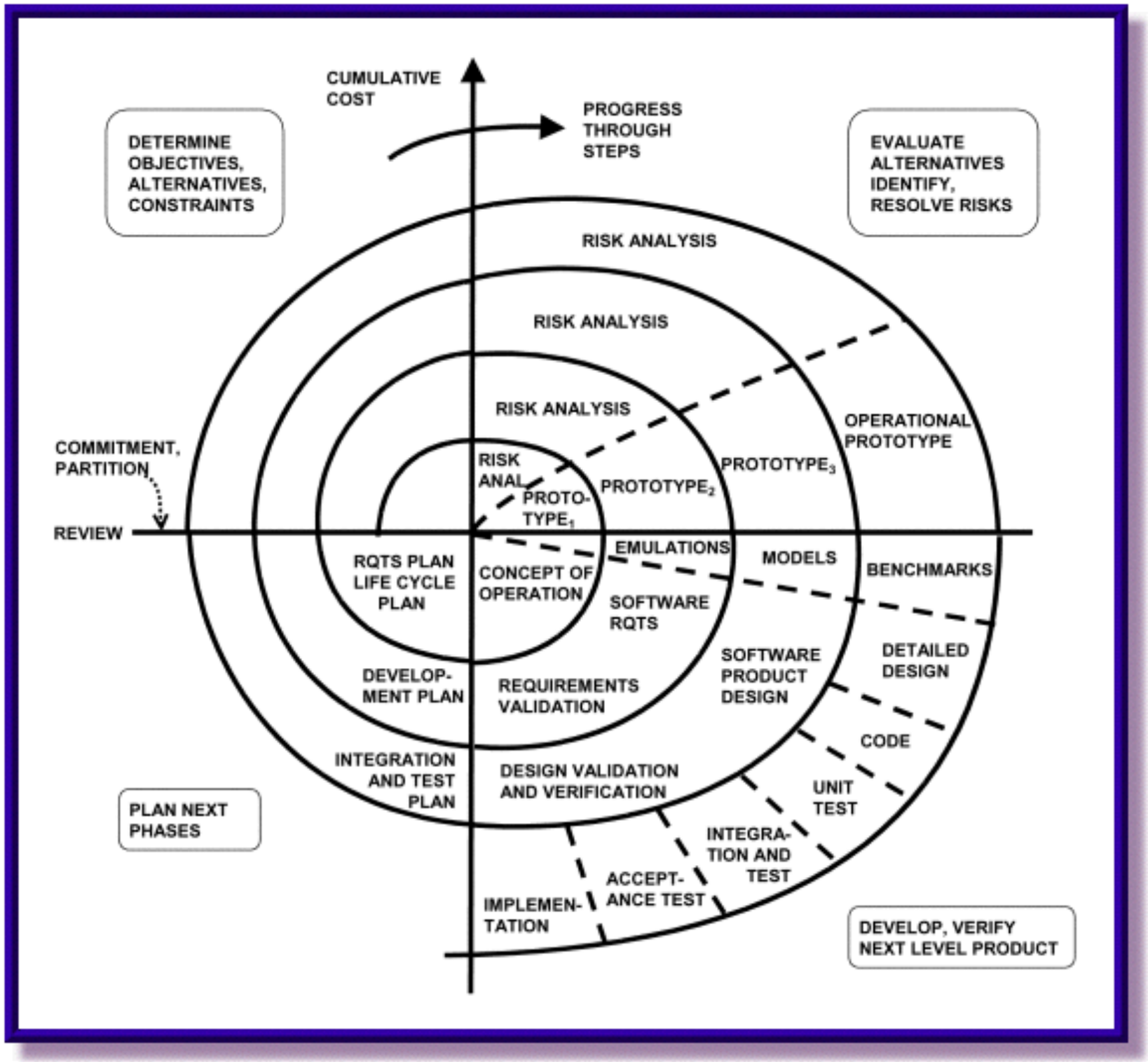
- Strong points
  - Helpful when requirements are not well understood
  - Flexible, for small-to-medium sized systems
  - Short turnaround, accommodates late changes
  - Prototype can be discarded, or evolved to final version
- Weak points
  - Development process is not visible
  - Evolution may create poorly structured systems
  - Special tools, special techniques required
  - Cannot use with large-scale projects requiring coordination

Spiral Lifecycle Model

an iterative
lifecycle model

[Barry Boehm, 1988]

evolutionary software process model that combines iterative nature of prototyping with controlled and systematic aspects of waterfall model



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Spiral Model: Features

- Reasons to adopt
  - Key idea is risk evaluation and reduction
  - Each cycle is a stage in the software process (here, requirements, analysis, design, implementation)
  - Other stages possible (eg interface, database, middleware)
  - Can choose to terminate after each risk evaluation
- Four stages
  - Set specific objectives for the current stage
  - Evaluate risks, explore alternative approaches
  - Develop and validate the current stage
  - Plan the next stage, when requested

Spiral Model: Evaluation

- Strong points
  - Combination of waterfall and prototyping approaches
  - Adapts to different projects with different stages
  - Clear software process for large-scale projects, iterative cycles last 6 months – 2 years
  - Clear evaluation of each stage, determines whether to proceed, or cut losses due to high risk
- Weak points
  - Projects can still be terminated before delivery
  - Late changes can still have serious consequences

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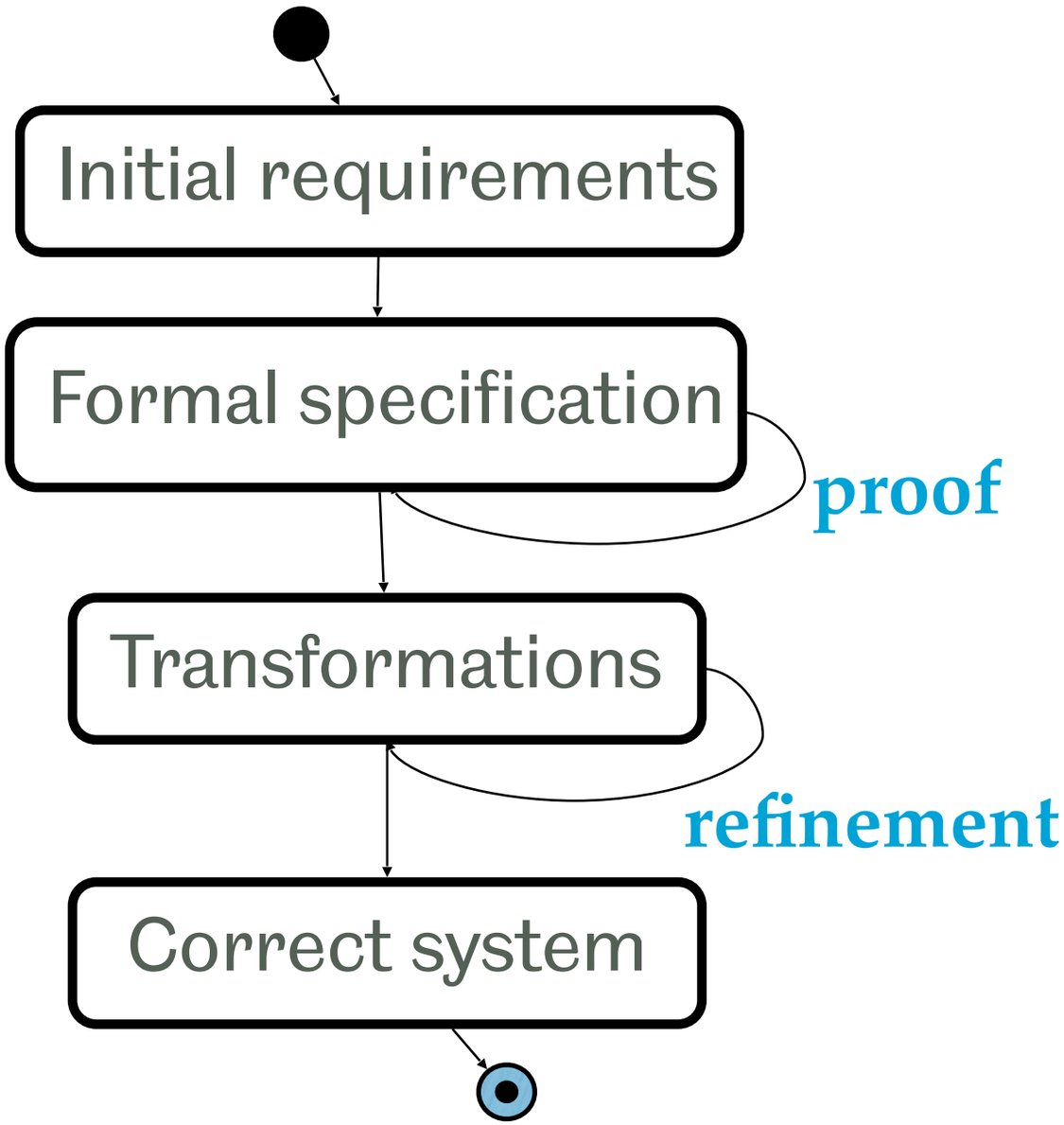
Formal Systems Development

- Reasons to adopt
  - Safety-critical, mission-critical systems
  - Medical treatment, aircraft, traffic control systems, etc.
- Software lifecycle
  - Construct formal spec. from initial requirements
  - Prove safety properties of the specification
  - Use refinement rules to transform into a correct implementation

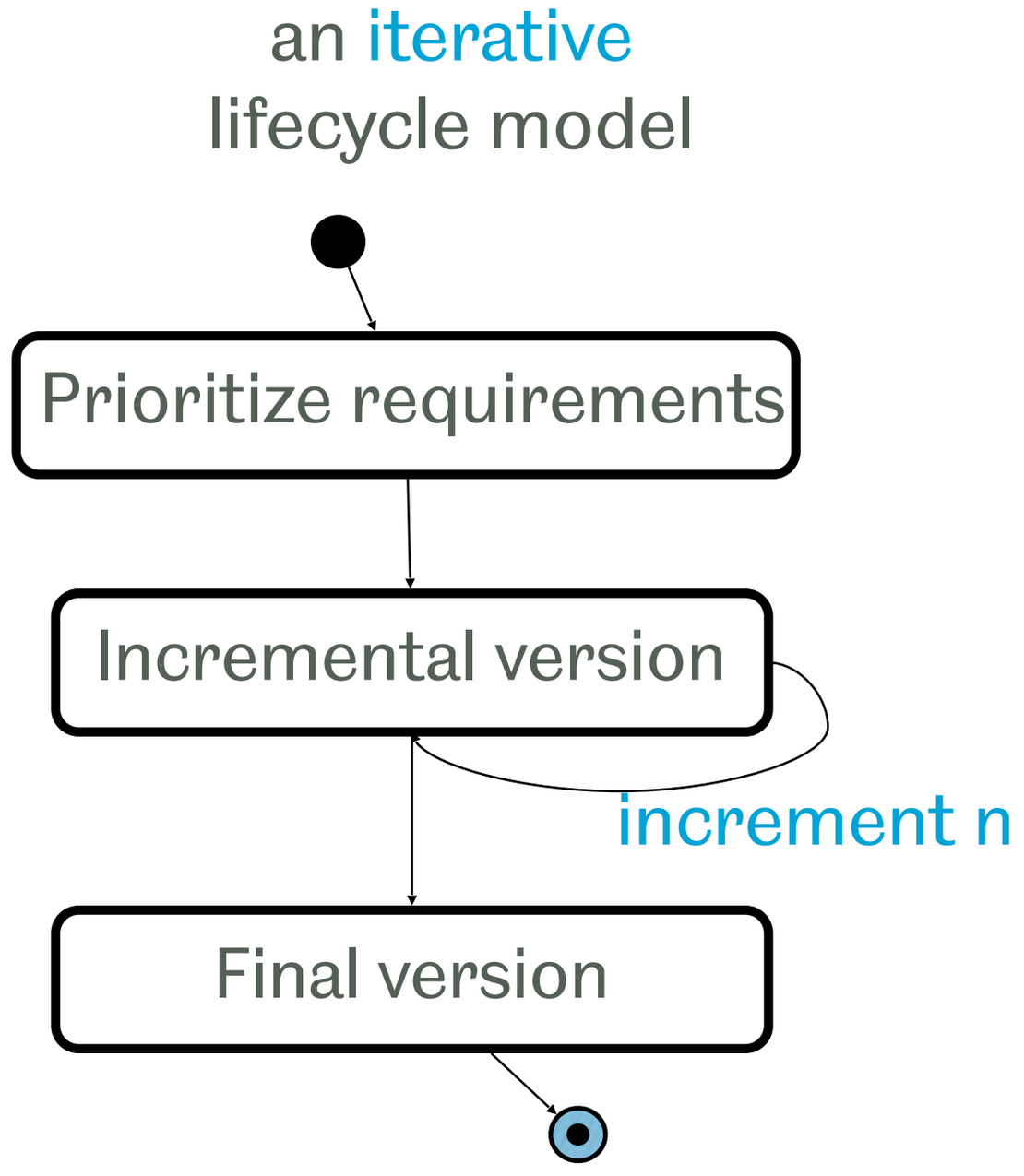


Formal Systems: Evaluation

- Strong points
  - Precise and error-free: correct by construction
  - Used for safety-critical, mission-critical systems
  - Proofs of correct specification (complete, consistent)
- Weak points
  - Requires specialised mathematical expertise
  - Perceived as difficult, or costly (but counter-examples)
  - Must still validate formal models against user requirements
  - Time-to-market is more compelling than correctness!
  - Non-formal approaches often seem adequate

Incremental Development

- Reasons to adopt
  - Time-to-market is critical
  - Must deliver something
- Software lifecycle
  - Sort requirements into prioritized increments
  - Deliver each increment within fixed time-box
  - Stop after the agreed number of iterations (often 4)



Incremental: Evaluation

- Strong points
  - Reduces gap between specification and delivery
  - Much lower risk of total project failure
  - Early increments can be prototypes
  - Highest priority services are delivered first
- Weak points
  - Increments have to be small, to deliver within the time-boxed period (avoid “feature creep”)
  - Hard to map large global requirements onto increments
  - Short time-box works best when requirements are well-understood and modular

Shift to Components

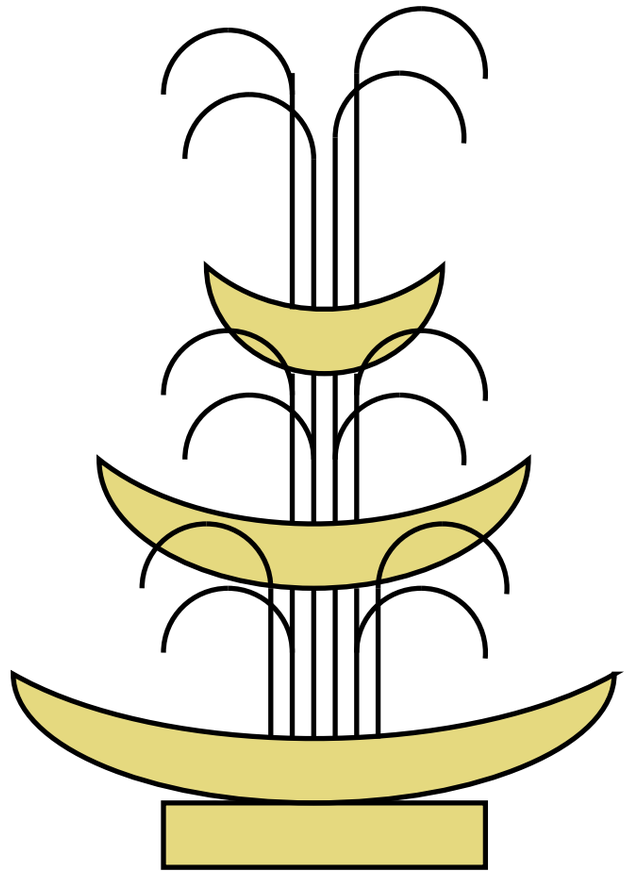
- Bespoke structured systems
  - 1970s: systems made-to-measure (at any cost!)
  - older structured languages: Fortran, Cobol
  - clear top-down design and stepwise refinement
- Component-based systems
  - 1990s: mix-and-match systems (fast, cheap)
  - object-oriented, component-based development
  - clear emphasis on component reuse
  - mixture of top-down design, bottom-up assembly

Component-Based Development

- Requirements phase
  - Collect system requirements as a set of tasks (top-down), or user-interactions: use cases (bottom-up)
  - Analyse requirements to map onto software components
- Construction phase
  - Build as much of the system as possible from existing components, or frameworks (component architectures)
  - Develop new components and integrate within existing framework
- Reuse/refactoring phase
  - Schedule framework for maintenance (refactoring – improve structure) and harvest any new reusable components

Fountain Lifecycle [Henderson-Sellers and Edwards, 1990]

- incremental
  - develop and deliver one task at a time
  - always a working prototype system
- iterative
  - revisit tasks where faults detected
  - revisit tasks where changes requested
- parallel
  - tasks developed independently
  - scope for multi-team development



Each task is like a jet in the fountain: many advance together, some reach the top immediately, others fall back to be caught and recycled.

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Components: Evaluation

- Strong points
  - Rapid development strategy, promotes reuse
  - Greatly reduced time-to-market (from 3rd project)
  - Reduces costs, and risks
- Weak points
  - High initial set-up costs (building frameworks, components)
  - Retrain personnel to fit new roles (eg: librarian)
  - Can lose control over the component set (adaptation)
  - Systems are sometimes forced to fit the framework and so don't deliver as expected

Agile Methods (XP)

- Agile methods philosophy
  - No “big design up-front” – just “user stories”
  - The production code base and saved tests are the only lasting deliverables
  - Short increments, daily builds, pass all tests
  - XP has “pair programming”: coder and critic
  - Anyone can modify the code base (extreme!)
  - Embrace change (extreme!)
- Examples
  - eXtreme Programming (XP) [Beck, 2000]
  - Scrum [Sutherland and Schwaber, 1996]

Agile Methods: Evaluation

- Strong points
  - Avoids unproductive, wasted documentation
  - Emphasis on testing (= meeting specification)
  - Developers enjoy the lightweight approach
  - System is always up-to-date
- Weak points
  - Inflexible process, cannot adapt to organisations
  - Expects good design to emerge by evolution
  - In practice, may fail for large systems that require coordination – no change tracking documentation

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  - Traditional Linear (waterfall, V model)
  - Incremental (rapid and evolutionary prototypes, spiral model)
  - Formal methods
  - Agile methods
  - Component re-use
  - ...

Software Engineering: Summary

- Software engineering covers all aspects of software production: technical, management process
- Software engineering includes software products, processes, models and people
- The software lifecycle consists of: requirements elicitation, analysis, design, implementation, testing, maintenance...
- Traditional process models are linear, good at coordinating large teams, but weak when handling change
- Radical process models are iterative, good at adapting to change and delivering, but weak at coordination
- The shift to software component technology requires a shift in the software development strategy