The Big Idea

Software Architecture

Chapter 1

The Origins

- Software Engineers have always employed software architectures
    - Very often without realizing it!
- Address issues identified by researchers and practitioners
    - Essential software engineering difficulties
    - Unique characteristics of programming-in-the-large
    - Need for software reuse
- Many ideas originated in other (non-computing) domains

Software Engineering Difficulties

- Software engineers deal with unique set of problems
  - Young field with tremendous expectations
  - Building of vastly complex, but intangible systems
  - Software is not useful on its own e.g., unlike a car, thus
  - It must conform to changes in other engineering areas
- Fred Brookes was the designer of IBM’s 360 OS and later a professor in a USA university

Software Engineering Difficulties (cont’d)

- According to his book “The Mythical Man Month”, which provides insights into the nature of software engineering:
- Some problems can be eliminated
  - These are Brooks’ “accidental difficulties”
- Other problems can be lessened, but not eliminated
  - These are Brooks’ “essential difficulties”

Accidental Difficulties

- Solutions exist
  - Possibly waiting to be discovered
- Past productivity increases result of overcoming
  - Inadequate programming constructs & abstractions
    - Remedied by high-level programming languages
    - Increased productivity by factor of five
    - Complexity was never inherent in program at all

Accidental Difficulties (cont'd)

- Past productivity increases result of overcoming (cont'd)
  - Viewing results of programming decisions took long time
    - Remedied by time-sharing
    - Turnaround time approaching limit of human perception
  - Difficulty of using heterogeneous programs
    - Addressed by integrated software development environments
    - Support task that was conceptually always possible

Essential Difficulties

- Only partial solutions exist for them, if any
- Cannot be abstracted away

  - Complexity
  - Conformity
  - Changeability
  - Intangibility

Complexity

- No two software parts are alike
  - If they are, they are abstracted away into one
- Complexity grows non-linearly with size
  - E.g., it is impossible to enumerate all states of program
  - Except perhaps “toy” programs

Conformity

- Software is required to conform to its
  - Operating environment
  - Hardware
  - Interfaces
  - Standards
  - Political decisions
  - ...
- Often “last kid on block”
- Perceived as most conformable

Changeability

- Change originates with
  - New applications, users, machines, standards, laws
  - Hardware problems
- Software is viewed as infinitely malleable

Intangibility

- Software is not embedded in space
  - Often no constraining physical laws
- No obvious representation
  - E.g., familiar geometric shapes

Pewter Bullets

- Ada, C++, Java and other high–level languages
- Object-oriented design/analysis/programming
- Artificial Intelligence
- Automatic Programming
- Graphical Programming
- Program Verification
- Environments & tools
- Workstations

Promising Attacks on Complexity (In 1987 by Brooks)

- Buy vs. Build
- Requirements refinement & rapid prototyping
  - Hardest part is deciding what to build (or buy?)
  - Must show product to customer to get complete specs
  - Need for iterative feedback

Promising Attacks on Complexity (cont'd)

- Incremental/Evolutionary/Spiral Development
  - Grow systems, don't build them
  - Good for morale
  - Easy backtracking
  - Early prototypes
- Great designers
  - Good design can be taught; great design cannot
  - Nurture great designers

Primacy of Design

- Software engineers collect requirements, code, test, integrate, configure, etc.
- An architecture-centric approach to software engineering places an emphasis on design
  - Design pervades the engineering activity from the very beginning
- But how do we go about the task of architectural design?

Analogy: Architecture of Buildings

- We all live in them
- (We think) We know how they are built
  - Requirements
  - Design (blueprints)
  - Construction
  - Use
- This is similar (though not identical) to how we build software
  - Requirements → Design → Detailed algorithms → Code implementing the algorithms → Deployment and use

Some Obvious Parallels

- Satisfaction of customers’ needs
- Specialization of labor
- Multiple perspectives of the final product
- Intermediate points where plans and progress are reviewed

Deeper Parallels

- Architecture is different from, but linked with the product/structure
  - Its major elements, their composition and arrangement, can be described, discussed and compared with those of other buildings
- Properties of structures are induced by the design of the architecture
  - E.g., a medieval castle with high, thick walls and narrow or nonexistent windows is designed that way so that it has excellent defensive properties
- The architect has a distinctive role and character

Deeper Parallels (cont'd)

- Process is not as important as architecture
  - Design and resulting qualities are at the forefront
  - Process is a means, not an end
- Architecture has matured over time into a discipline
  - The notion of "architectural styles", e.g., "Gothic cathedral", "Swiss chalet", etc.
  - Architectural styles as sets of constraints, e.g., a Swiss chalet has steep roofs to minimize the load from snow
  - Styles also offer a wide range of solutions, techniques and palettes of compatible materials, colors, and sizes

More About the Architect

- A distinctive role and character in a project
- Very broad training
- Amasses and leverages extensive experience
- A keen sense of aesthetics
- Deep understanding of the domain
  - Properties of structures, materials, and environments
  - Needs of customers

More about the Architect (cont’d)

- Even first-rate programming skills are insufficient for the creation of complex software applications
  - But are they even necessary?

Limitations of the Analogy …

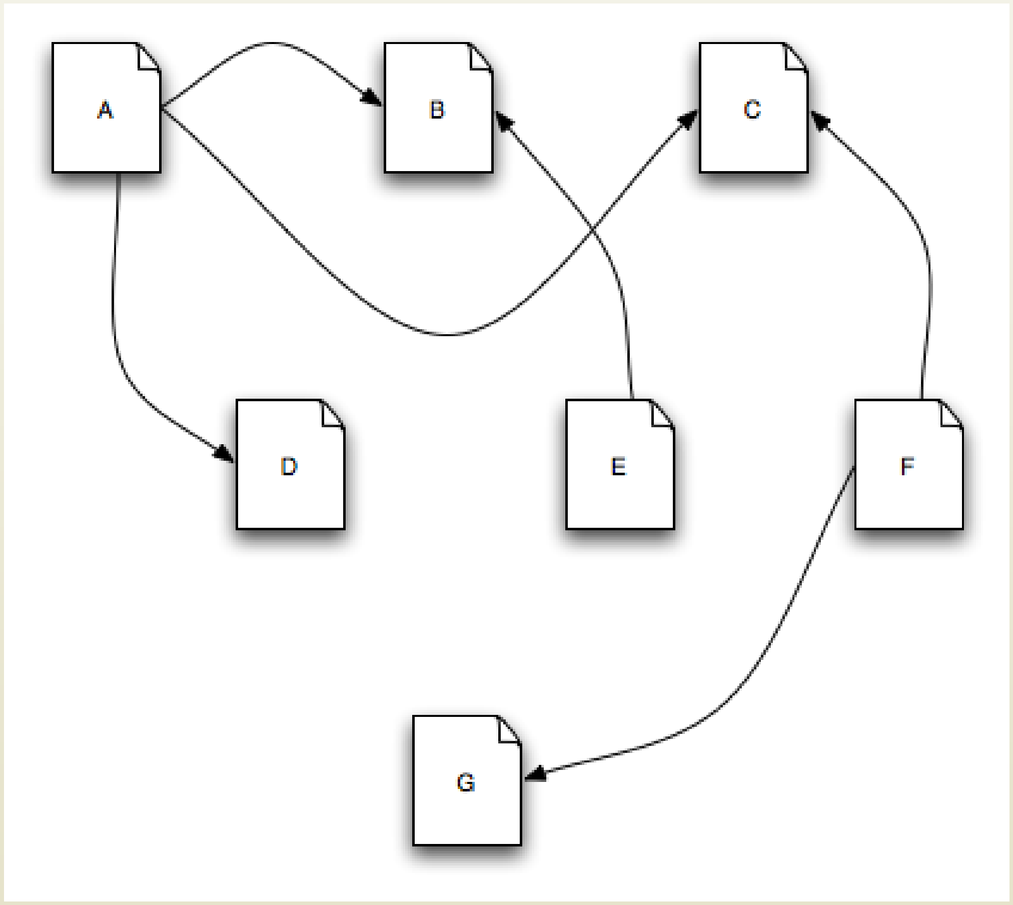
- We know a lot about buildings, much less about software
- The nature of software is different from that of building architecture
- Software is much more malleable than physical materials
- The two "construction industries" are very different
- Software deployment has no counterpart in building architecture
- Software is a machine; a building is not
  - The dynamic character of software creates difficulties to designers with no counterpart in building design

…But Still Very Real Power of Architecture (the Big Idea)

- Giving preeminence to architecture offers the potential for
  - Intellectual control
  - Conceptual integrity
  - Adequate an effective basis for reuse
  - Effective project communication
  - Management of a set of variant systems
- Limited-term focus on architecture will not yield significant benefits!
- Software Architecture must be at the very heart of software system design and development

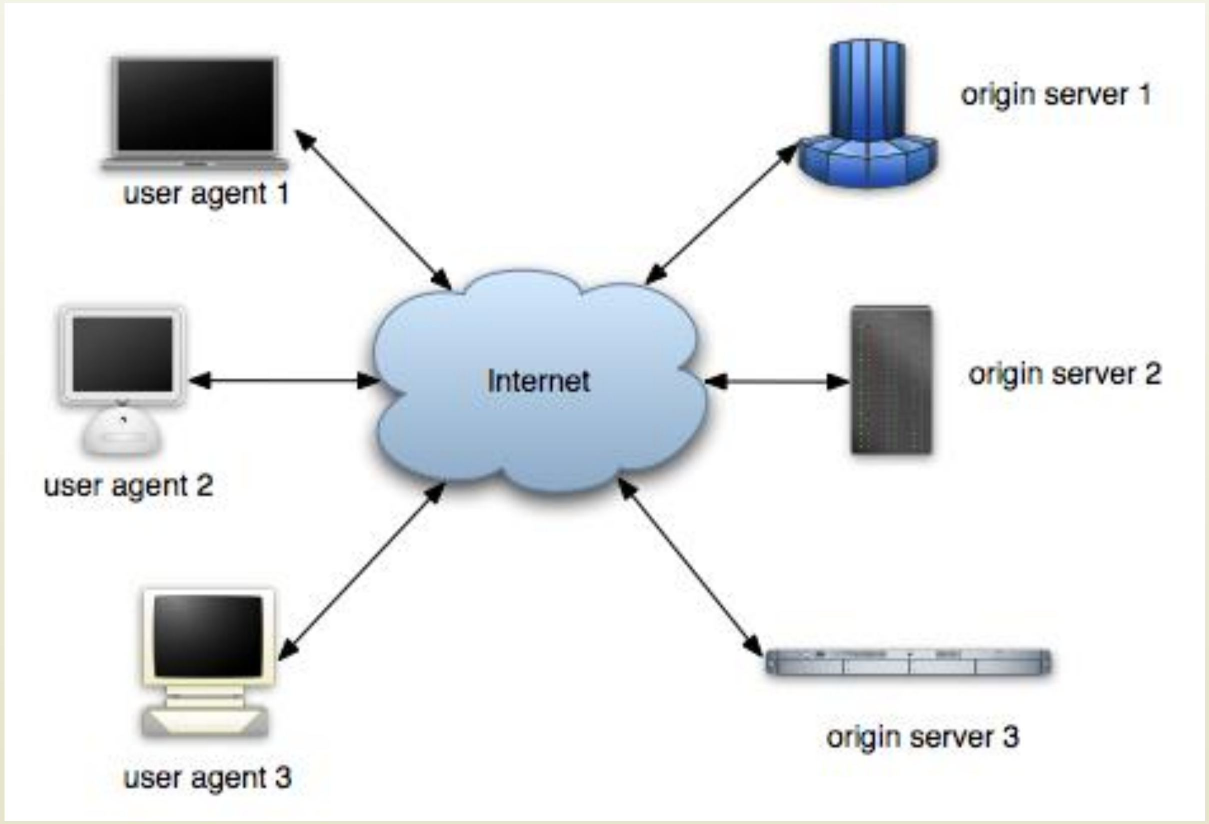
Architecture in Action: WWW

- This is the Web
- Represented as a set of data (documents `A` to `G`) and their interrelationships in the form of a hypertext document



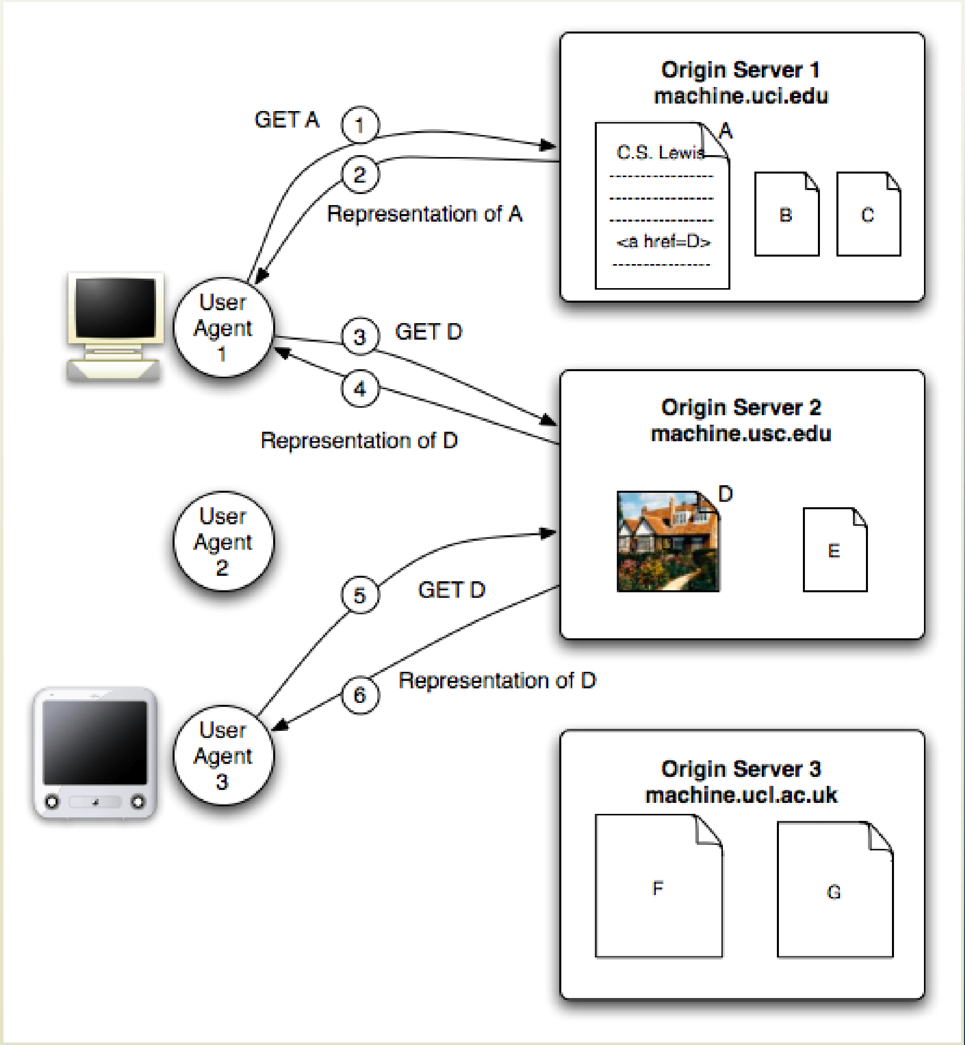
Architecture in Action: WWW

- So is this
- Represented as a collection of computers interconnecte d through the Internet



Architecture in Action: WWW

- And this
- Represented as a set of user agents and origin servers, interacting according to the HTTP protocol
- This is typically the way users perceive the Web



WWW in a (Big) Nutshell

- The Web is a collection of resources, each of which has a unique name known as a uniform resource locator, or "URL"
- Each resource denotes, informally, some information
- URI's can be used to determine the identity of a machine on the Internet, known as an origin server, where the value of the resource may be ascertained
- Communication is initiated by clients, known as user agents, who make requests of servers
  - Web browsers are common instances of user agents

WWW in a (Big) Nutshell (cont'd)

- Resources can be manipulated through their representations
  - HTML is a very common representation language used on the Web
- All communication between user agents and origin servers must be performed by a simple, generic protocol (HTTP), which offers the command methods GET, POST, etc.
- All communication between user agents and origin servers must be fully self-contained (so-called "stateless interactions")

WWW’s Architecture

- Architecture of the Web is wholly separate from the code
  - The architecture is the set of principal design decisions that determine the key elements of of the Web and their interelationships
- There is no single piece of code that implements the architecture; just looking at a single piece of code, or even all the code on a single machine, will not explain the Web structure
- There are multiple pieces of code that implement the various components of the architecture
  - E.g., different Web browsers

WWW’s Architecture (cont’d)

- Stylistic constraints of the Web’s architectural style are not apparent in the code but at the same time the effects of the constraints are evident in the Web
- One of the world’s most successful applications is only understood adequately from an architectural vantage point
- There are important observations, but still:
  - Why were these particular decisions made?
  - Why were these decisions important and not others?
  - Why did similar systems that made slightly different decisions failed but the Web succeeded?

Architecture in Action: Desktop

- Remember pipes and filters in Unix?
  - `ls invoices | grep -e august | sort`
- Application architecture can be understood based on very few rules
- Applications can be composed by non-programmers
  - Akin to Lego blocks
- A simple architectural concept that can be comprehended and applied by a broad audience

Architecture in Action: Product Line

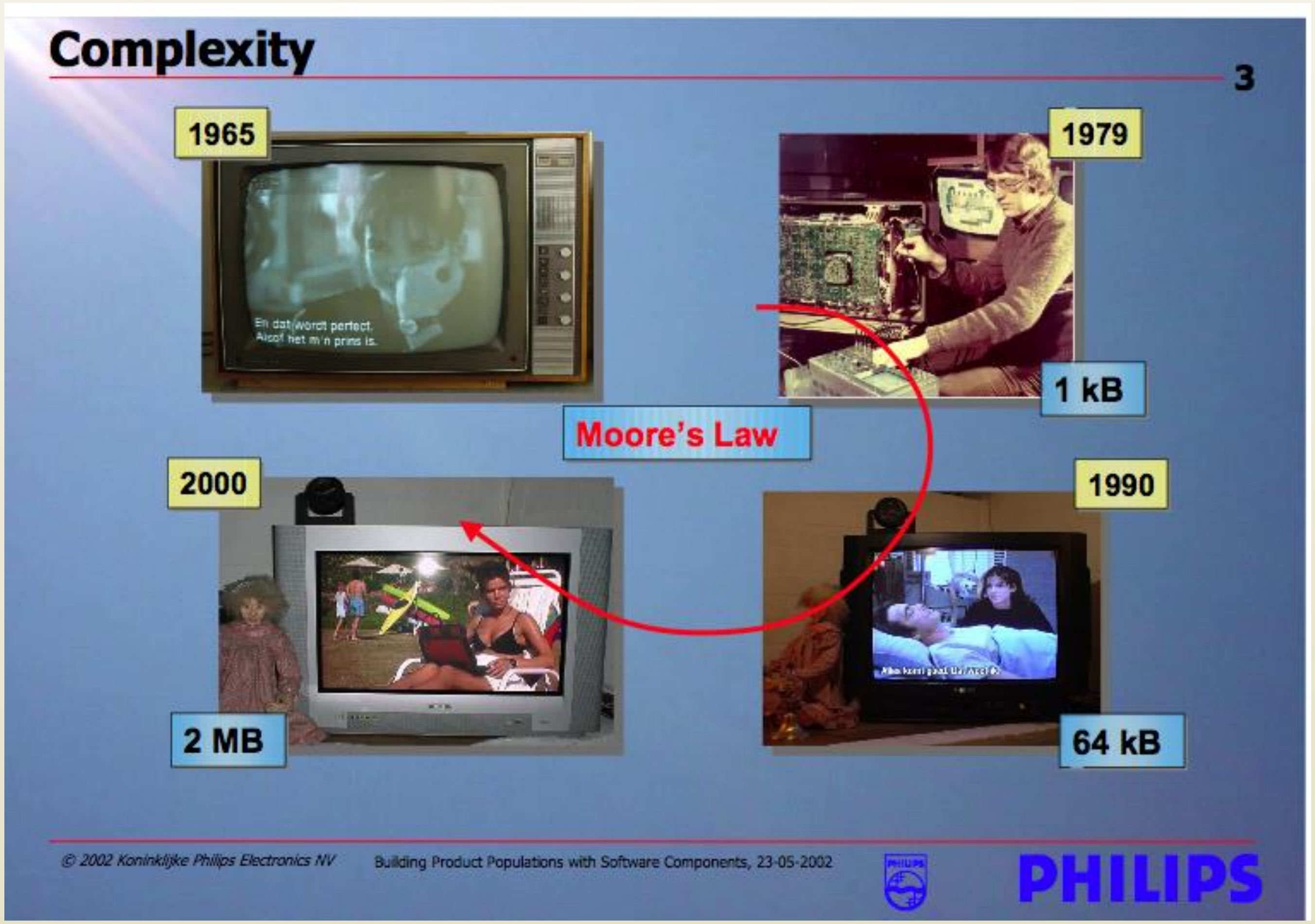
- Motivating example
  - A consumer is interested in a 35-inch HDTV with a built-in DVD player for the North American market

    Such a device might contain upwards of a million lines of embedded software

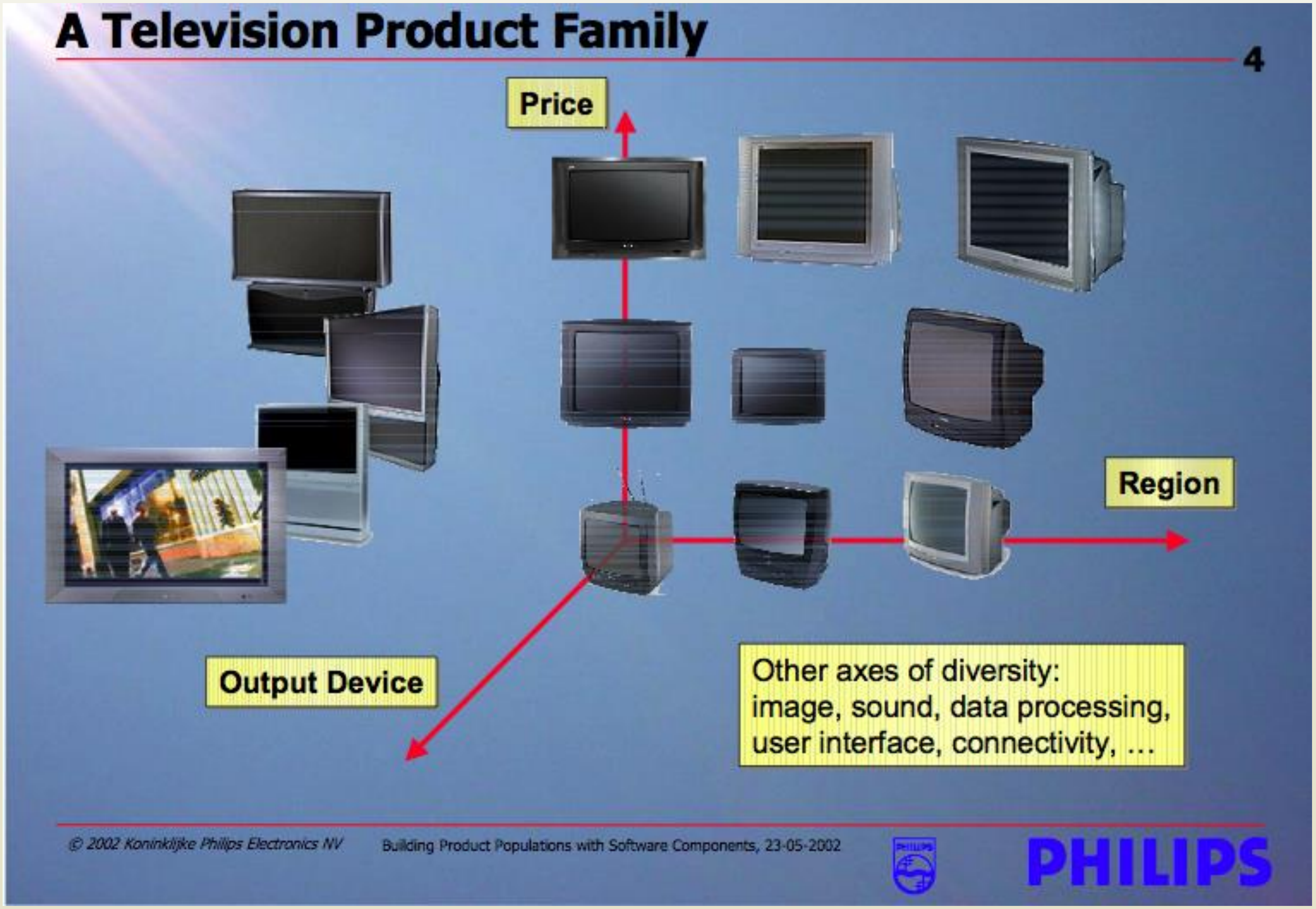
    This particular television/DVD player will be very similar to a 35-inch HDTV without the DVD player, and also to a 35-inch HDTV with a built-in DVD player for the European market, where the TV must be able to handle PAL or SECAM encoded broadcasts, rather than North America’s NTSC format

    These closely related televisions will similarly each have a million or more lines of code embedded within them

Growing Sophistication of Consumer Devices


Complexity
3
1965
1979
1 kB
Moore's Law
2000
1990
2 MB
64 kB
© 2002 Koninklijke Philips Electronics NV
Building Product Populations with Software Components, 23-05-2002
PHILIPS

Families of Related Products


A Television Product Family
4
Price
Region
Output Device
Other axes of diversity: image, sound, data processing, user interface, connectivity, …
© 2002 Koninklijke Philips Electronics NV
Building Product Populations with Software Components, 23-05-2002
PHILIPS

The Necessity and Benefit of PLs

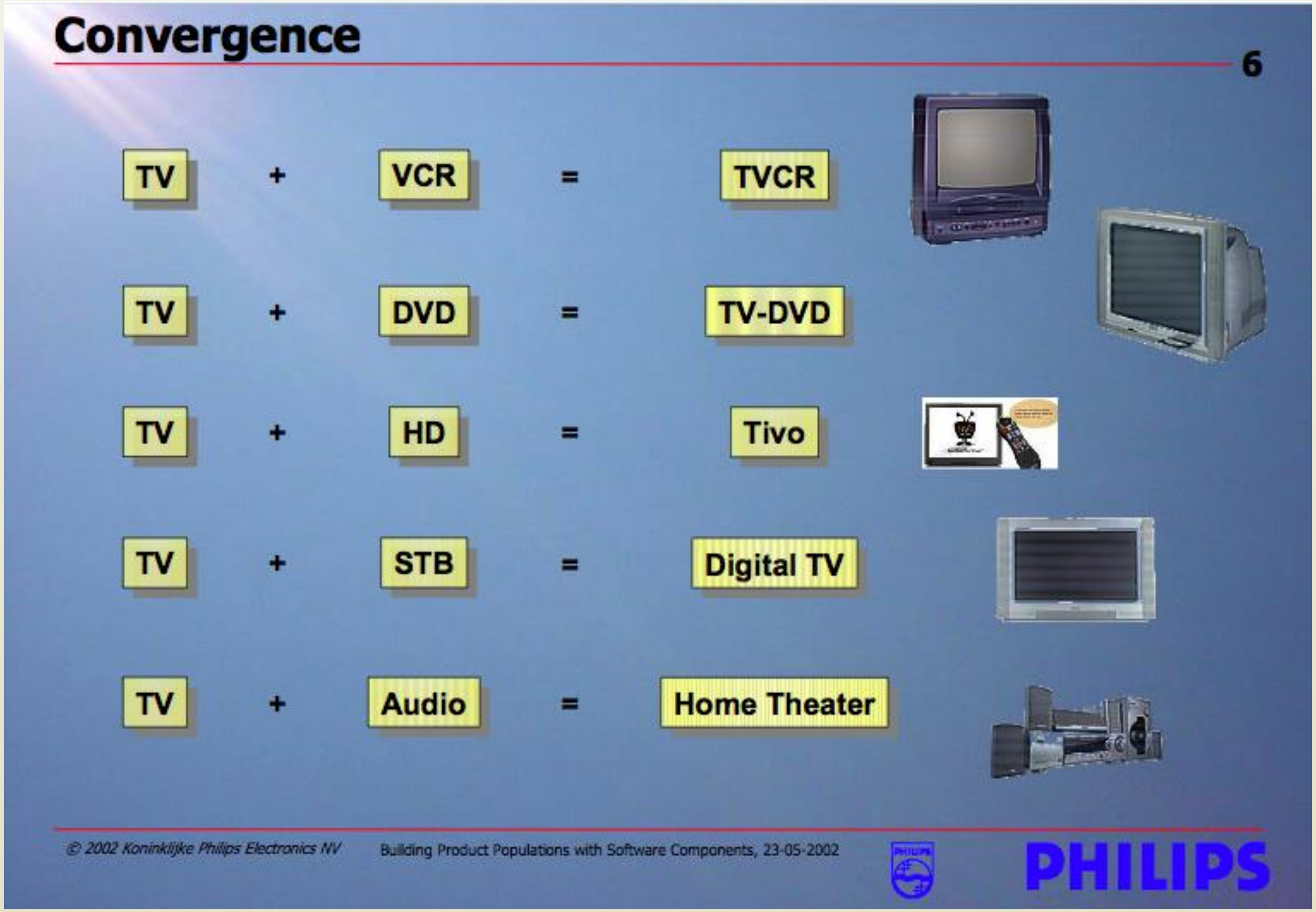
- Building each of these TVs from scratch would likely put Philips out of business
- Reusing structure, behaviors, and component implementations is increasingly important to successful business practice
  - It simplifies the software development task
  - It reduces the development time and cost
  - it improves the overall system reliability
- Recognizing and exploiting commonality and variability across products

Reuse as the Big Win

- Architecture: reuse of
  - Ideas
  - Knowledge
  - Patterns
  - Engineering guidance
  - Well-worn experience

- Product families: reuse of
  - Structure
  - Behaviors
  - Implementations
  - Test suites …

Added Benefit – Product Populations



Convergence

6

TV + VCR = TVCR

TV + DVD = TV-DVD

TV + HD = Tivo

TV + STB = Digital TV

TV + Audio = Home Theater

© 2002 Koninklijke Philips Electronics NV

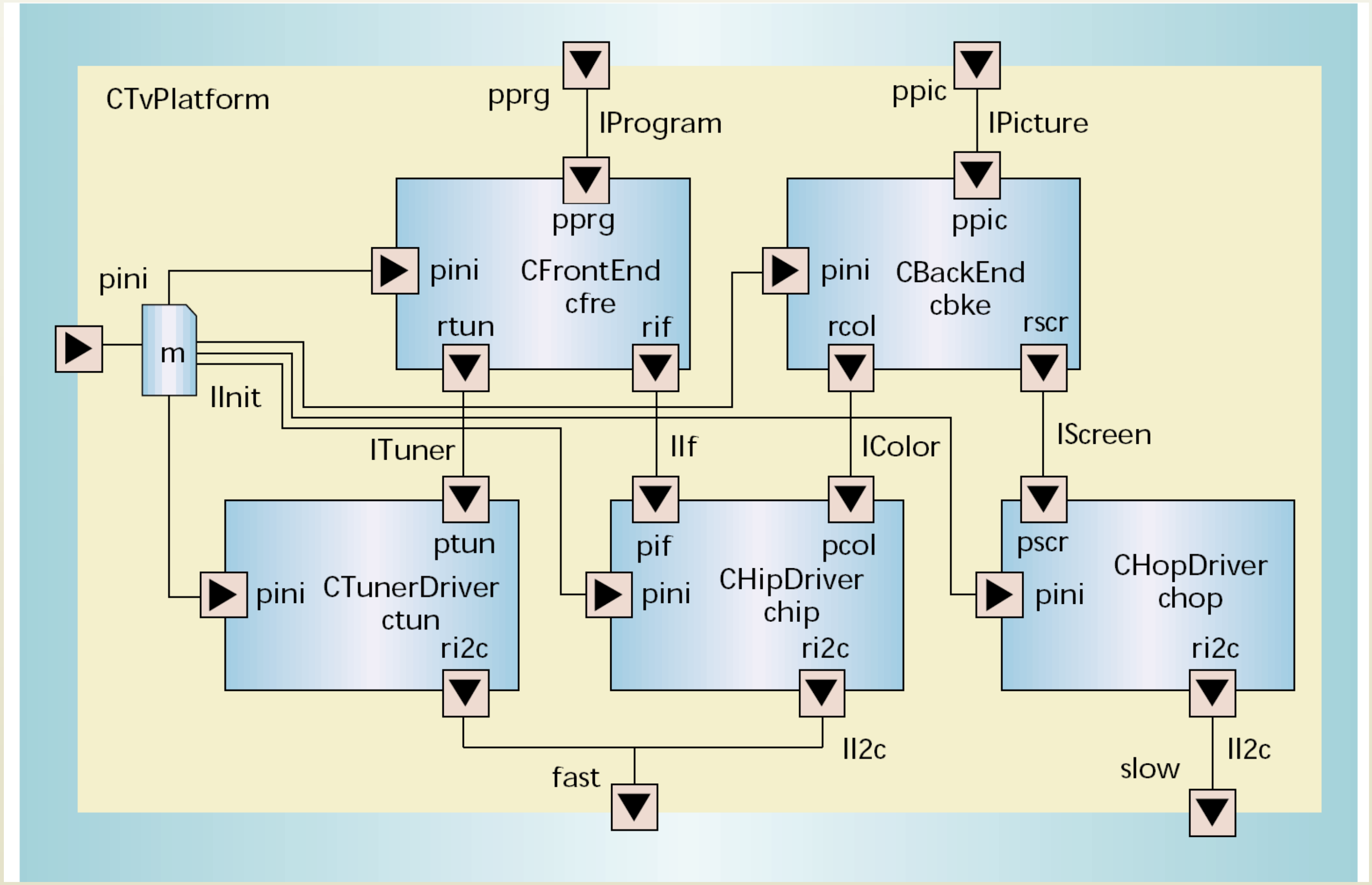
Building Product Populations with Software Components, 23-05-2002

PHILIPS

Philips' Koala Technology

- Koala supports commonality and variability across products
- The product family notion extends to the growing amount of software embedded in the different devices
- A software system is implemented as a collection of interacting components
  - Each component exports a set of services via a set of *provides* interfaces
  - It also defines its its dependencies (h/w or s/w) via a set of *requires* interfaces

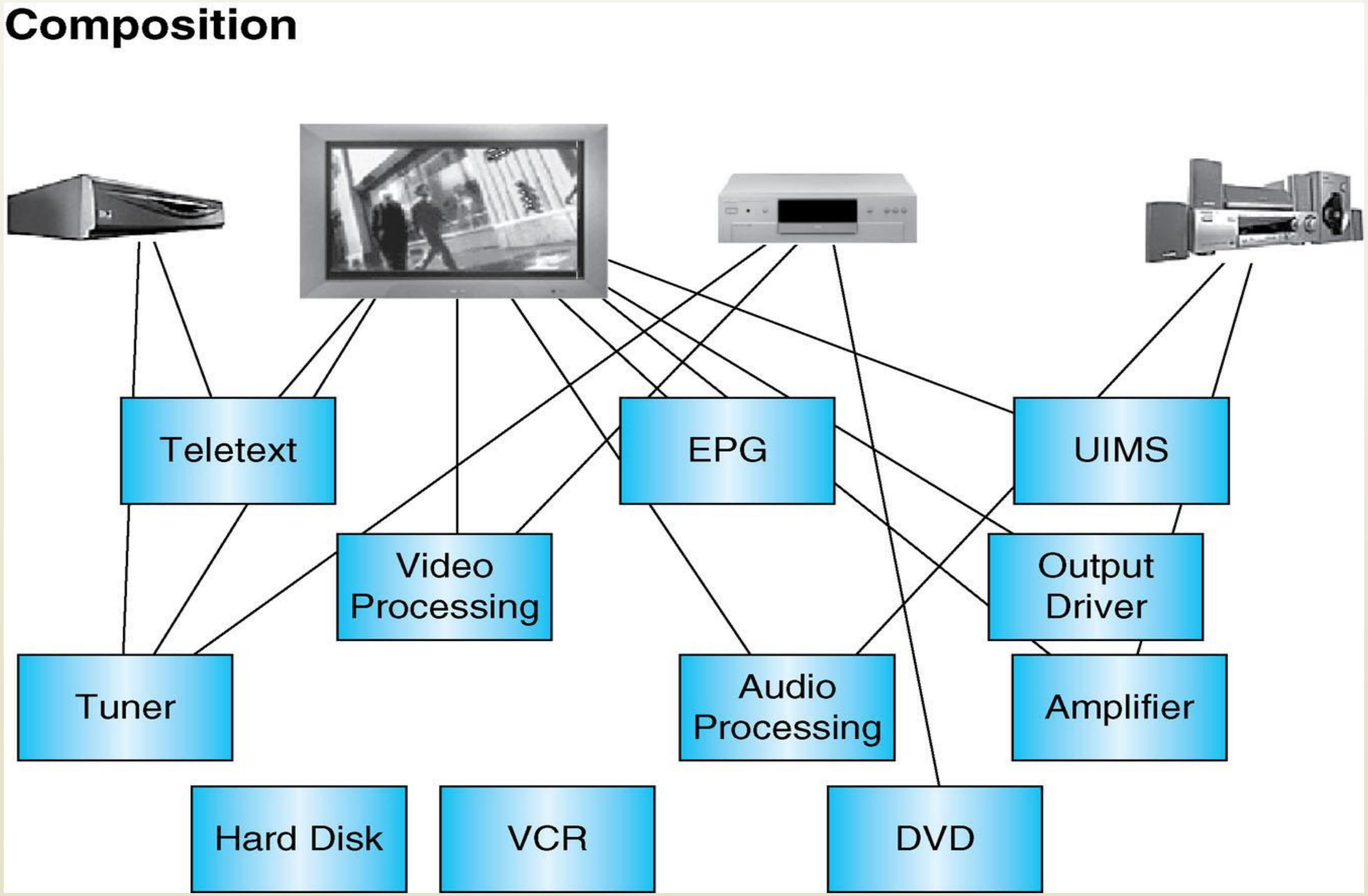
The Centerpiece – Architecture



Philips' Koala Technology (cont'd)

- Koala uses three separate mechanisms to support variability across products
  - *Diversity interfaces* allow a component to import configuration-specific properties, which are external to the component
  - *Switches* are connecting elements that allow a single component to interact with one of a set of components, depending on the value of a given run-time parameter
  - *Optional interfaces* allow a component to either provide or require additional functionality

Combining Existing Products



Summary

- Software is complex
- So are buildings
  - And other engineering artifacts
  - Building architectures are an attractive source of analogy
- Software engineers can learn from other domains
- They also need to develop—and have developed—a rich body of their own architectural knowledge and experience