Software Architecture in Practice

Paul C. Clements
Software Engineering Institute
Carnegie Mellon University
Pittsburgh, PA 15213-3890 USA

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Schedule and Outline

0900 - 0915	**Introductions**
0915 - 0945	**The Architecture Business Cycle**
0945 -1000	**What is architecture?**
1000 - 1030	**Why is architecture important?**
1030 - 1045	**Break**
1045 - 1115	**Architectural structures**
1115 - 1200	**New developments in software architecture**

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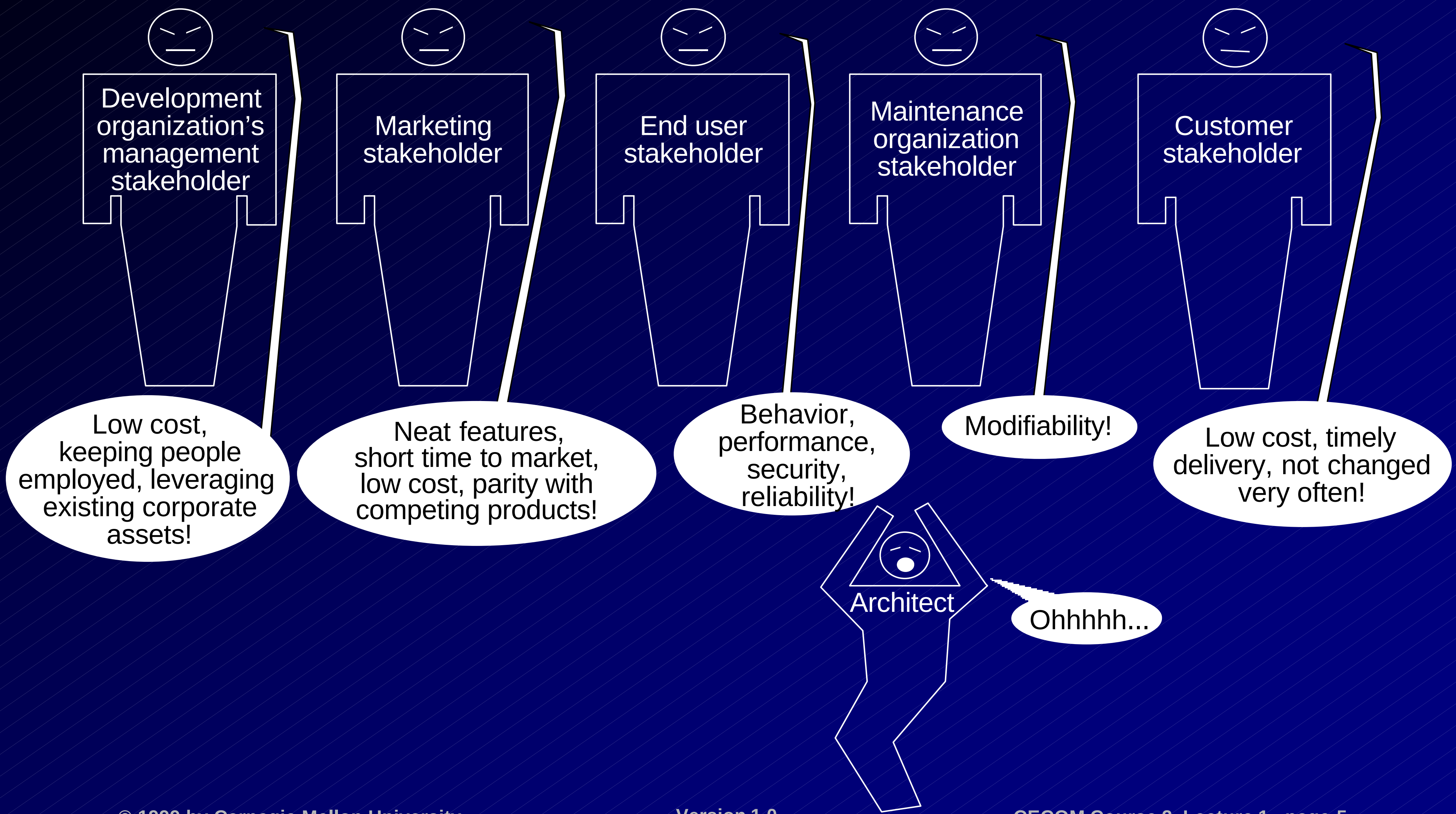
Factors Influencing Architectures

Architectures are influenced by

- **stakeholders of a system**
- **technical and organizational factors**
- **architect's background**

Stakeholders of a System



Development Organization Concerns

Business issues

- **investing in, and then amortizing the infrastructure**
- **keeping cost of installation low**
- **investing in, and then utilizing personnel**

Organizational structure issues

- **furthering vested interests, e.g.,**
  - **maintaining an existing database organization**
  - **supporting specialized expertise**
- **maintaining the standard method of doing business**

Technical Environment

Current trends: today's information system will likely employ a

- database management system
- Web browser for delivery and distribution across platforms

This was not true 10 years ago.

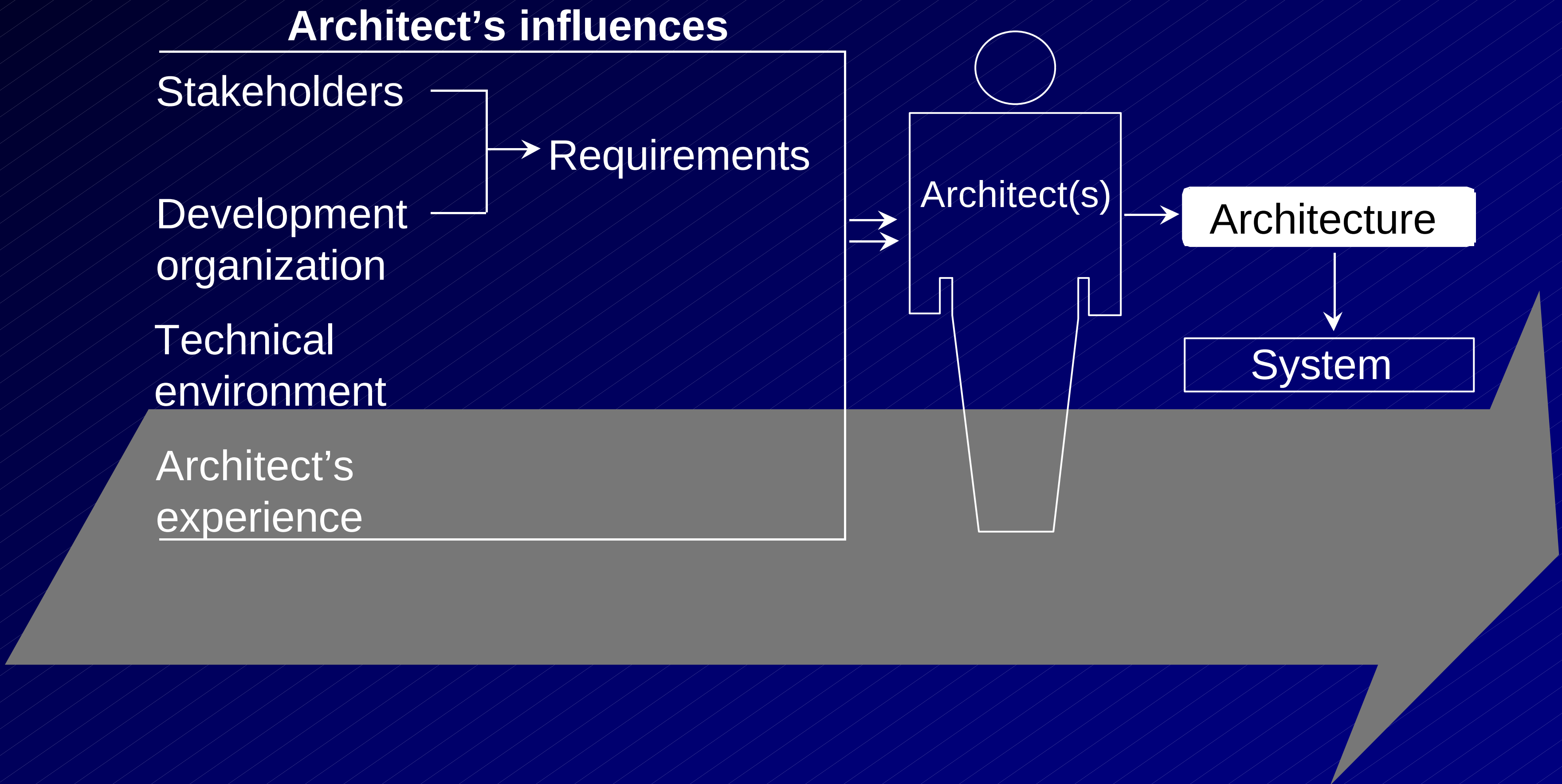
Available technology: decisions on using a centralized or decentralized system depend on processor cost and communication speed; both are changing quantities.

Architect's Background

Architects develop their mindset from their past experiences.

- **Prior good experiences will lead to replication of prior designs.**
- **Prior bad experiences will be avoided in the new design.**

Summary: Influences on the Architect



What Makes a Good Architect?

People skills: must be able to

- **negotiate competing interests of stakeholders**
- **promote inter-team collaboration**

Technical skills: must understand

- **the relationships between qualities and structures**
- **current technology**
- **that most requirements for an architecture are not written down in any requirements document**

Communication skills: must be able to

- **clearly convey the architecture to teams (both verbally and in writing)**
- **listen to and understand multiple viewpoints**

Factors Influenced by Architectures

Structure of the development organization

Enterprise goals of the development organization

Customer requirements

Architect's experience

Technical environment

The architecture itself

Architecture Influences the Development Organization Structure

Short term: work units are organized around architectural units for a particular system under construction.

Long term: when company constructs a collection of similar systems, organizational units reflect common components (e.g., operating system unit or database unit).

Architecture Influences the Development Organization Enterprise Goals

Development of a system may establish a foothold in the market niche.

Being known for developing particular kinds of systems becomes a marketing device.

Architecture becomes a leveraging point for additional market opportunities and networking.

Architecture Influences Customer Requirements

Knowledge of similar fielded systems leads customers to ask for particular features.

Customers will alter their requirements on the basis of the availability of existing systems.

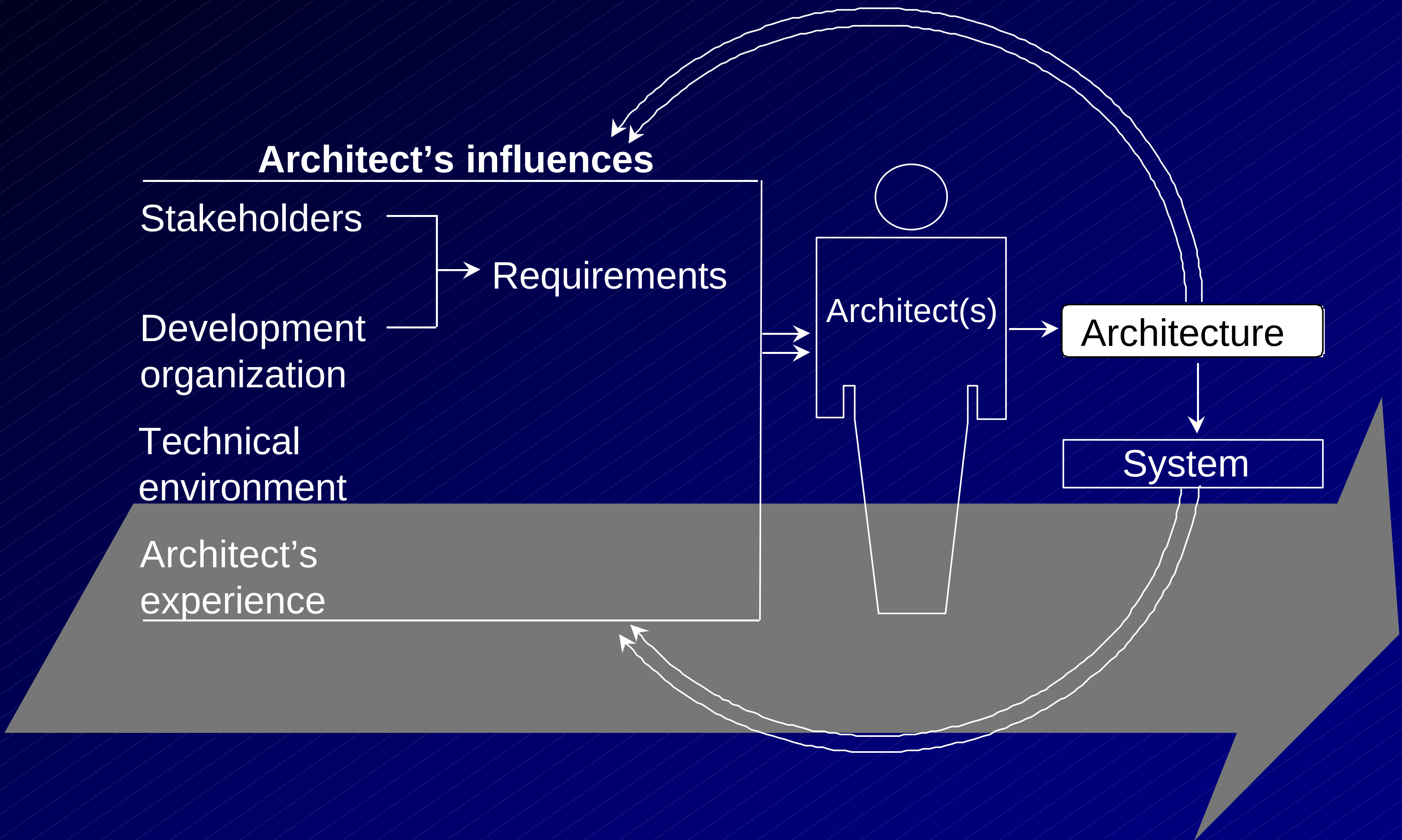
Architecture Influences the Architect's Experience and Technical Environment

Creation of a system affects the architect's background.

Occasionally, a system or an architecture will affect the technical environment.

- **the WWW for information systems**
- **the three-tier architecture for database systems**

Architecture Business Cycle (ABC)



ABC Summary

Architecture involves more than just technical requirements for a system. It also involves non-technical factors, such as the

- **architect's background**
- **development environment**
- **business goals of the sponsoring organization**

Architecture influences the factors that affect it.

- **Architects learn from experience.**
- **The development environment is expanded and altered.**
- **Businesses gain new marketing possibilities.**

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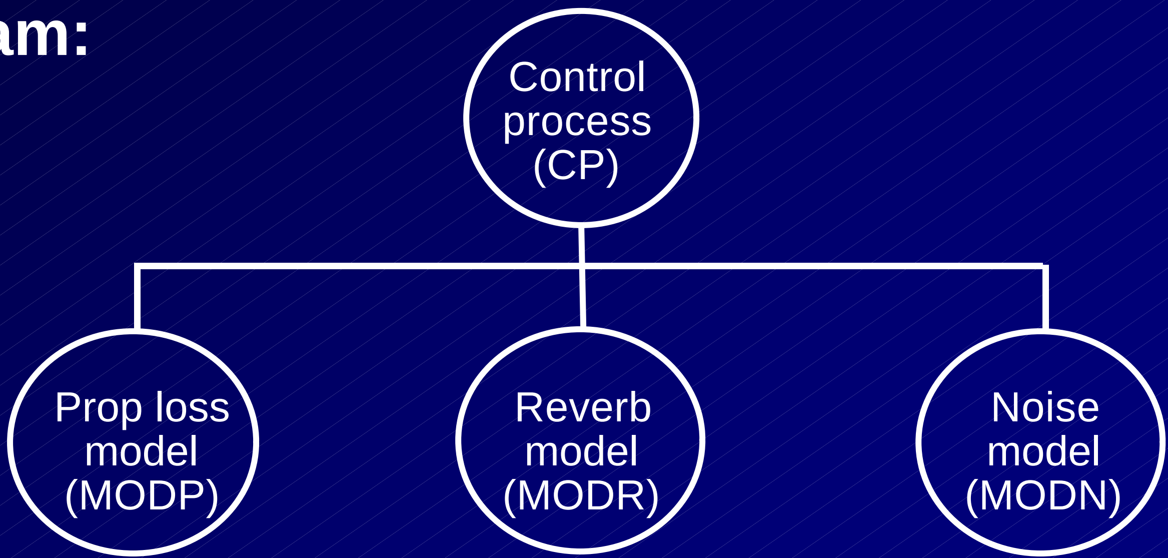
Some Usual Descriptions of Architecture

“Components and connectors”

“Overall structure of system”

A diagram:



What's Wrong with "Components and Connectors?"

What kind of component?

- **task? process?**
- **object? program? function?**
- **library? compilation unit?**
- **processor?**

What kind of connector?

- **calls? invokes? signals? uses? data flow?**
- **subclass?**
- **runs with? excludes?**
- **co-located with?**

What's Wrong with "Overall Structure?"

***Which* structure? Software is composed of *many* structures.**

- **module**
- **task**
- **uses**
- **logical**
- **functional**

When seeing boxes and lines, we must ask

- **What do the boxes represent?**
- **What do the arrows mean?**

What's Wrong with the Diagram?

Same questions as the previous slide.

- **What kind of components?**
- **What kind of connectors?**
- **What structures?**
- **What do the boxes and arrows mean?**

Plus new questions

- **What is the significance of the layout?**
- **Why is control process on a higher level?**

Box and arrow drawings alone are not architectures; rather, they are a starting point.

The Definition of Software Architecture

The software architecture of a program or computing system is the structure or structures of the system, which comprise software components, the externally visible properties of those components, and the relationships among them.

Notice this means that

- **box-and-line drawings alone are *not* architectures, but a starting point.**
- **architecture includes behavior of components**

Architectural Style -1

Architectural style: ***a description of component and connector types and a pattern of their runtime control and/or data transfer*** **[Shaw 96]**

Architectural styles are a set of canonical architectural solutions to problems.

Styles are underspecified architectures. They suggest patterns of runtime interaction, and topologies of components.

Architectural Style -2

A style may be thought of as

- **a set of constraints on an architecture**
- **an abstraction for a set of related architectures**

Styles appearing in the literature include

- **client server**
- **cooperating process**
- **data-centered**
- **layered**

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Importance of Architecture to a Development Organization’s Business

Software for a system or group of systems

- **provides leverage over a marketplace**
- **provides a vehicle for management oversight**
- **provides for the scoping of products**
- **can be used as a sales tool (e.g., conforms to industry standards)**

Enterprise architectures enable

- **shorter learning time**
- **specialized tool support**
- **sharing of infrastructure costs among systems**

Important of Architecture to a Development Project

Architecture is important for three primary reasons.

1. **It provides a vehicle for communication among stakeholders.**
2. **It is the manifestation of the earliest design decisions about a system.**
3. **It is a transferable, reusable abstraction of a system.**

Communication Vehicle

Architecture is a frame of reference in which competing interests may be exposed, negotiated.

- **negotiating requirements with users**
- **keeping customer informed of progress, cost**
- **implementing management decisions and allocations**

Architecture constrains the implementation and therefore the implementors

- **implementations must conform to architecture**
- **(global) resource allocation decisions constrain implementations of individual components**

Result of Early Design Decisions -1

The architecture dictates organizational structure for development/maintenance efforts. Examples include

- **division into teams**
- **units for budgeting, planning**
- **basis of work breakdown structure**
- **organization for documentation**
- **organization for CM libraries**
- **basis of integration**
- **basis of test plans, testing**
- **basis of maintenance**

Once decided, architecture is extremely hard to change!

Result of Early Design Decisions -2

Architecture permits/precludes achievement of a system's desired quality attributes. For example:

If you desire	Examine
performance	inter-component communication
modifiability	component responsibilities
security	inter-component communication, specialized components (e. g., kernels)
scalability	localization of resources
ability to subset	inter-component usage
reusability	inter-component coupling

The architecture influences qualities, but does not guarantee them.

Result of Early Design Decisions -3

An architecture helps users reason about and manage change (about 80% of effort in systems occurs *after* deployment).

Architecture divides all changes into three classes.

- *local:* modifying a single component
- *non-local:* modifying several components
- *architectural:* modifying the gross system topology, communication, and coordination mechanisms

A good architecture is one in which the most likely changes are also the easiest to make.

Reusable Model

An architecture is an abstraction: a one-to-many mapping (one architecture, many systems).

Architecture is the basis for product (system) commonality. Entire product lines can share a single architecture.

Systems can be built from large, externally developed components that are tied together via architecture.

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Architectural Structures -1

In a house, there are plans for

- **rooms**
- **electrical wiring**
- **plumbing**
- **ventilation**

Each of these constitutes a “view” of the house.

- **used by different people**
- **used to achieve different qualities in the house**
- **serves as a description and prescription**

So it is with software architecture.

Architectural Structures -2

Which structures are used, and why?

Common structures include

- **module**
- **process**
- **uses**
- **calls**
- **data flow**
- **class**
- **physical**

A structure provides a *view* of the architecture.

Module Structure

Components: modules, work assignments

Relations: "is a submodule of," "shares a secret with"

Used: as a basis of team structure and resource allocation

Affected attributes include: maintainability, understandability

Process Structure

Components: tasks, processes

Relations: "synchronizes with," "excludes," "preempts"

Used: to tune system runtime performance, exploit multiprocessing hardware

Affected attributes include: performance

Uses Structure

Components: procedures

Relations: "assumes the correct presence of"

Used: to engineer subsets, supersets

Affected attributes include: reusability, testability, incremental development

Calls Structure

Components: procedures

Relation: invokes

Used: to trace control flow; for debugging

Affected attributes include: buildability, testability, maintainability, understandability

Data Flow Structure

Components: programs, modules

Relation: “may send data to”

Used: for traceability of functionality

Affected attributes include: performance, correctness, accuracy

Class Structure

Components: objects

Relation: "inherits from," "is instance of"

Used: to exploit similarity among objects

Affected attributes include: development time, maintainability

Physical Structure

Components: tasks, processes, processors

Relation: "resides on same processor"

Used: to manage process-to-processor allocation

Affected attributes include: performance

What Are Structures Used For?

Descriptive: documentation vehicle for

- **current development**
- **future development**
- **managers**
- **customers**

To document the architecture, document the views.

Prescriptive: engineering tool to help achieve qualities

Architectural Structures Summary

Structures are related to each other in complicated ways.

In some systems, different structures collapse into a single one. (For example, process structure may be the same as module structure for extremely small systems.)

Which Views Should I Use?

Rational Unified Process: 4+1 views

Siemens 4-view model

(C4ISR framework prescribes 3 views, but these are not views of the *software* architecture. More later.)

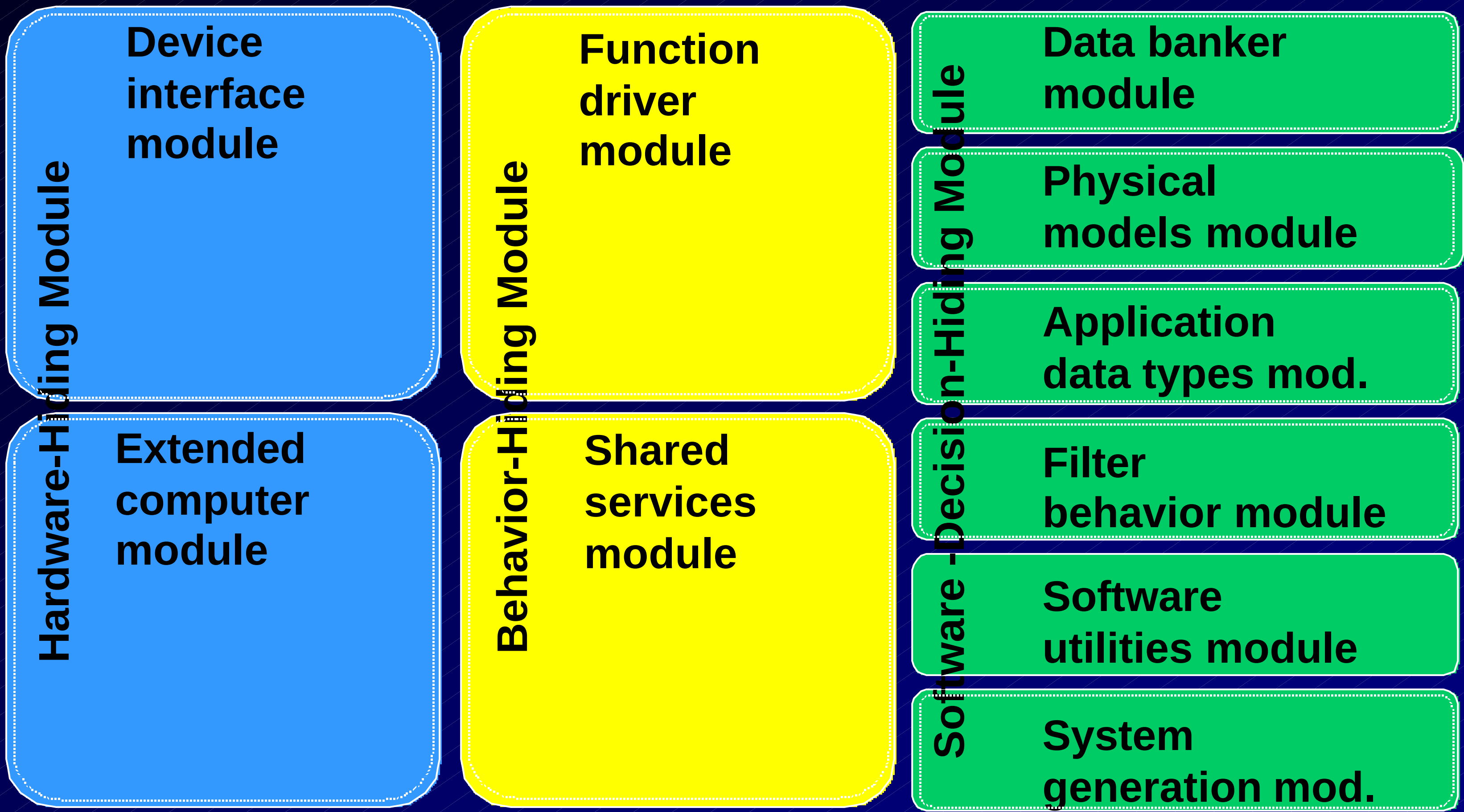
What to do? Choose the structures that are useful to the system being built and to the achievement of qualities that are important to you.

Architectural Structures Example: A-7E Corsair II Aircraft

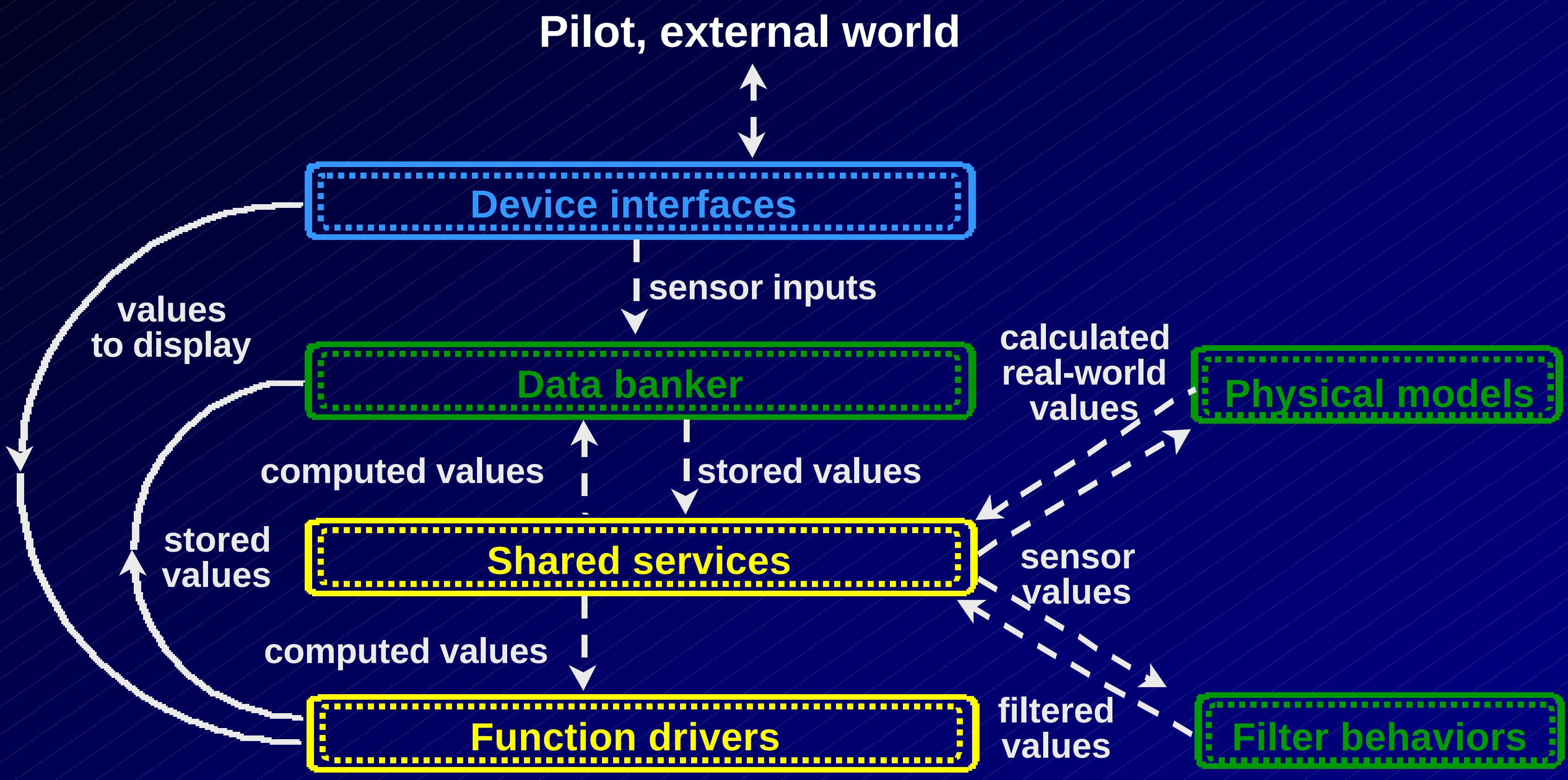
U. S. carrier-based, light attack aircraft, used from the 1960s through the 1980s

Small computer on board for navigation, weapons delivery

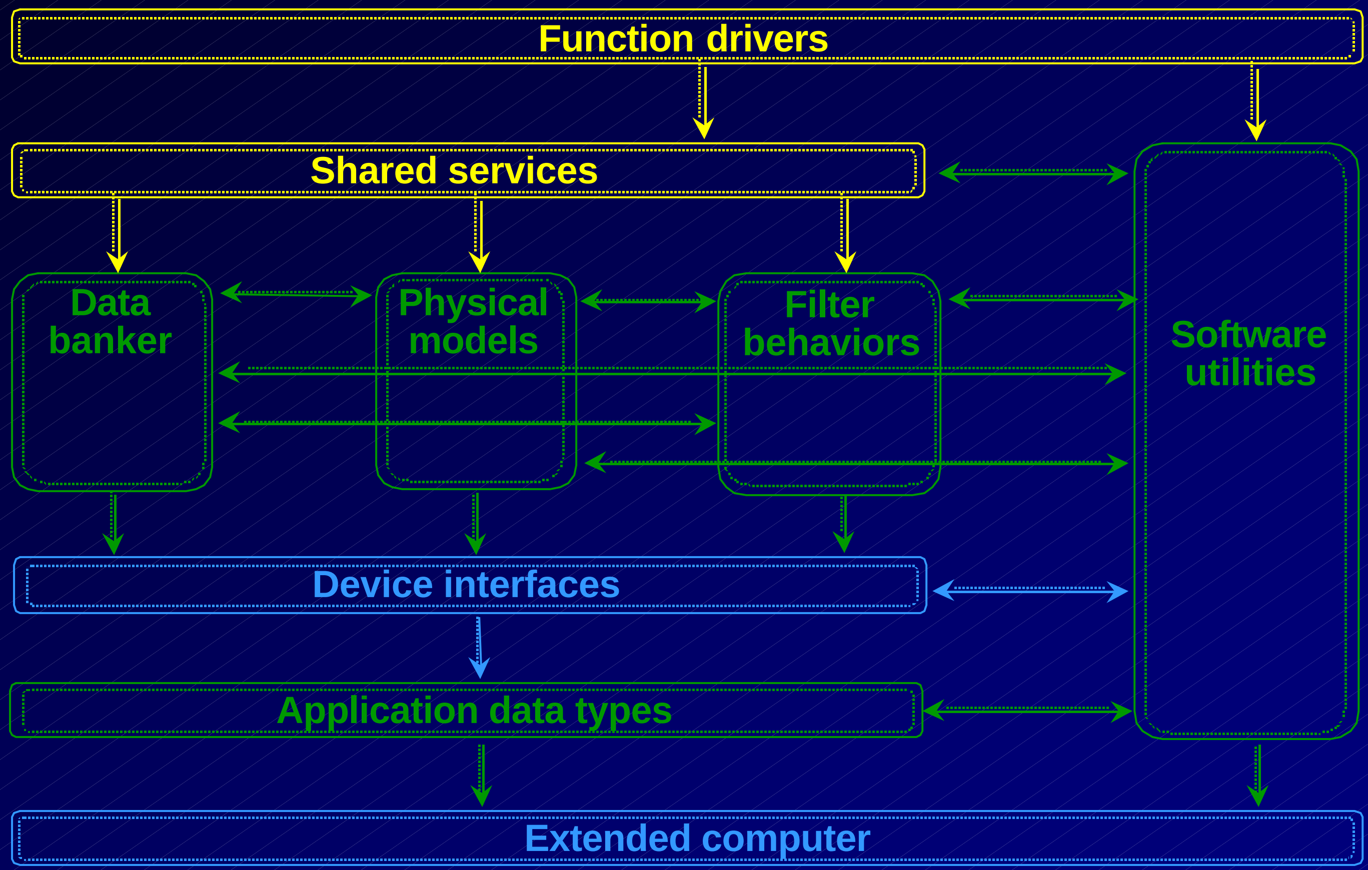
A-7E Module Structure (2 Levels)



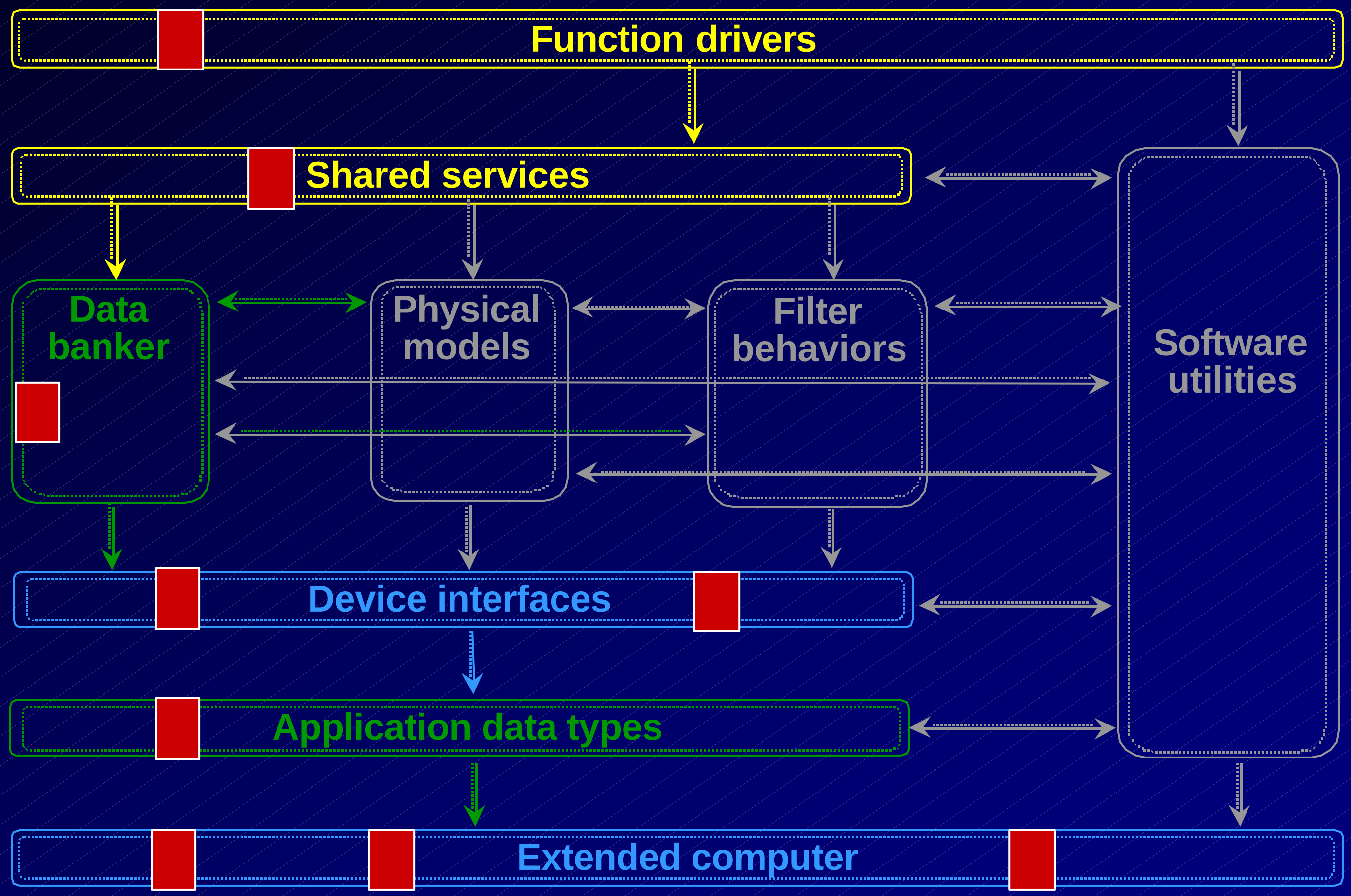
Data Flow View



"Uses" View


Function drivers
Shared services
Data banker
Physical models
Filter behaviors
Software utilities
Device interfaces
Application data types
Extended computer

A-7E Subset: Display HUD Altitude



Lecture Summary -1

Architecture is important because

- **it provides a communication vehicle among stakeholders**
- **it is the result of the earliest design decisions about a system**

An architecture is composed of many structures, documented as *views*, which are software components and their relationships.

Each structure provides engineering leverage on different qualities. Engineer and document the structures that help to achieve your desired qualities.

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- Software product lines
- Aspect-oriented software development
- Predictable assembly from certifiable components

CelsiusTech Systems

Swedish defense contractor

- approximately 2000 employees
- about $300 million in annual sales

Long-time supplier of naval shipboard command and control systems

1985: Disaster Struck!

CelsiusTech marketers landed two large contracts simultaneously.

- **1,000,000 SLOC each (estimated)**
- **greater complexity of requirements than before**

CelsiusTech realized they could not fulfill both contracts unless they started doing business in a totally new way.

- **Earlier systems were troublesome to integrate and had cost schedule overruns.**
- **Hiring was not an option: there was a shortage of engineers.**

CelsiusTech's Response

Business strategy

- create a product family
- make the software scaleable over a wide range of systems

Technical strategy

- create a new generation of system
  - hardware, software
  - supporting development approach
- configure systems from product family; each new project was added to the family

What CelsiusTech Did

Assembled a small expert architecture team with

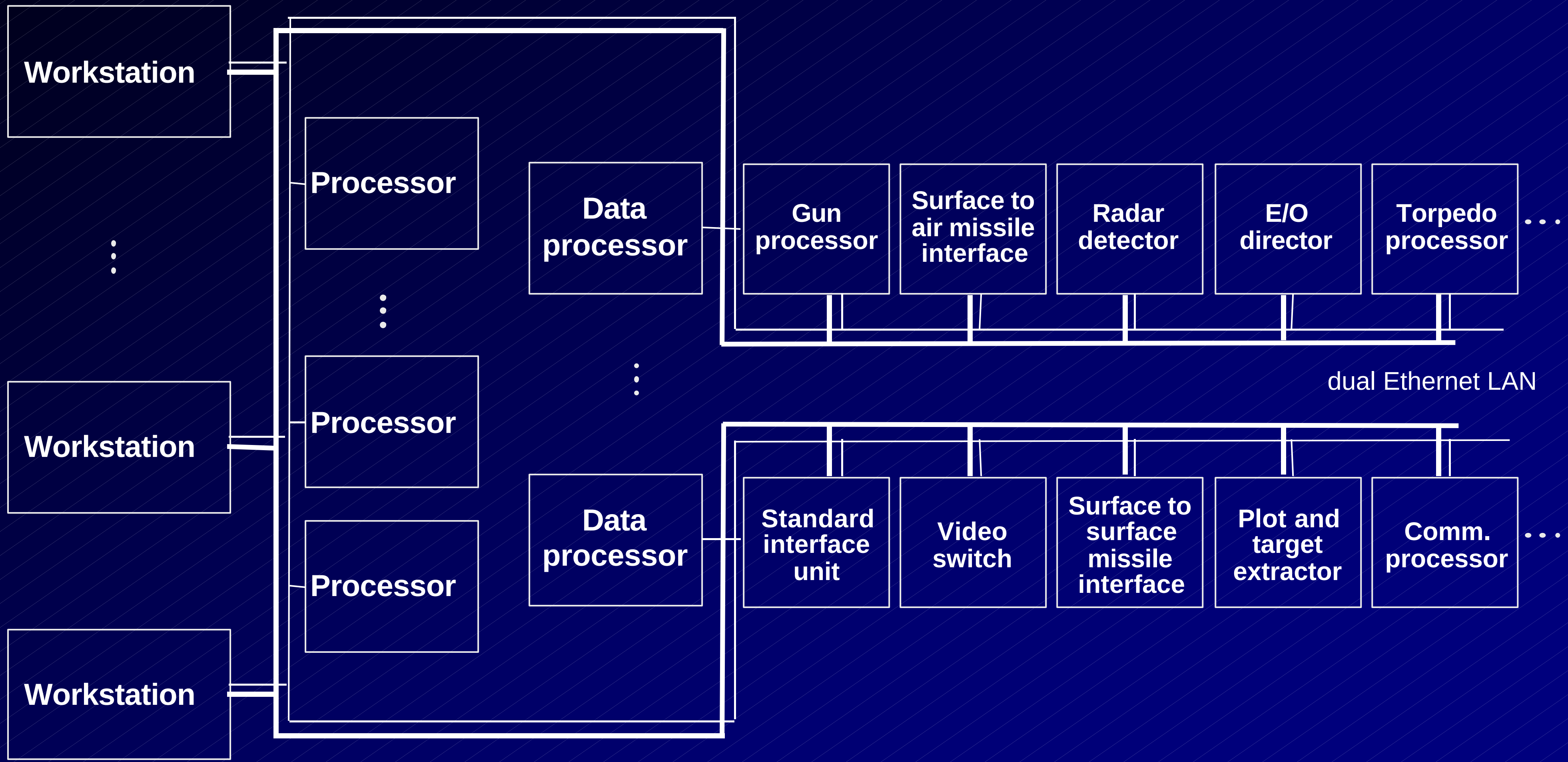
- **extensive domain knowledge**
- **previous systems experience**
- **Objective: produce architecture that would suffice for *both* systems *plus* new systems in the same domain.**

Produce software components that populated this architecture

- **Components were flexible, configurable across a wide variety of envisioned uses**

System-building became a matter of integration, not construction.

SS2000 System Architecture



Typical System Configuration

15-30 nodes on LAN

30-70 CPUs

100-300 Ada programs

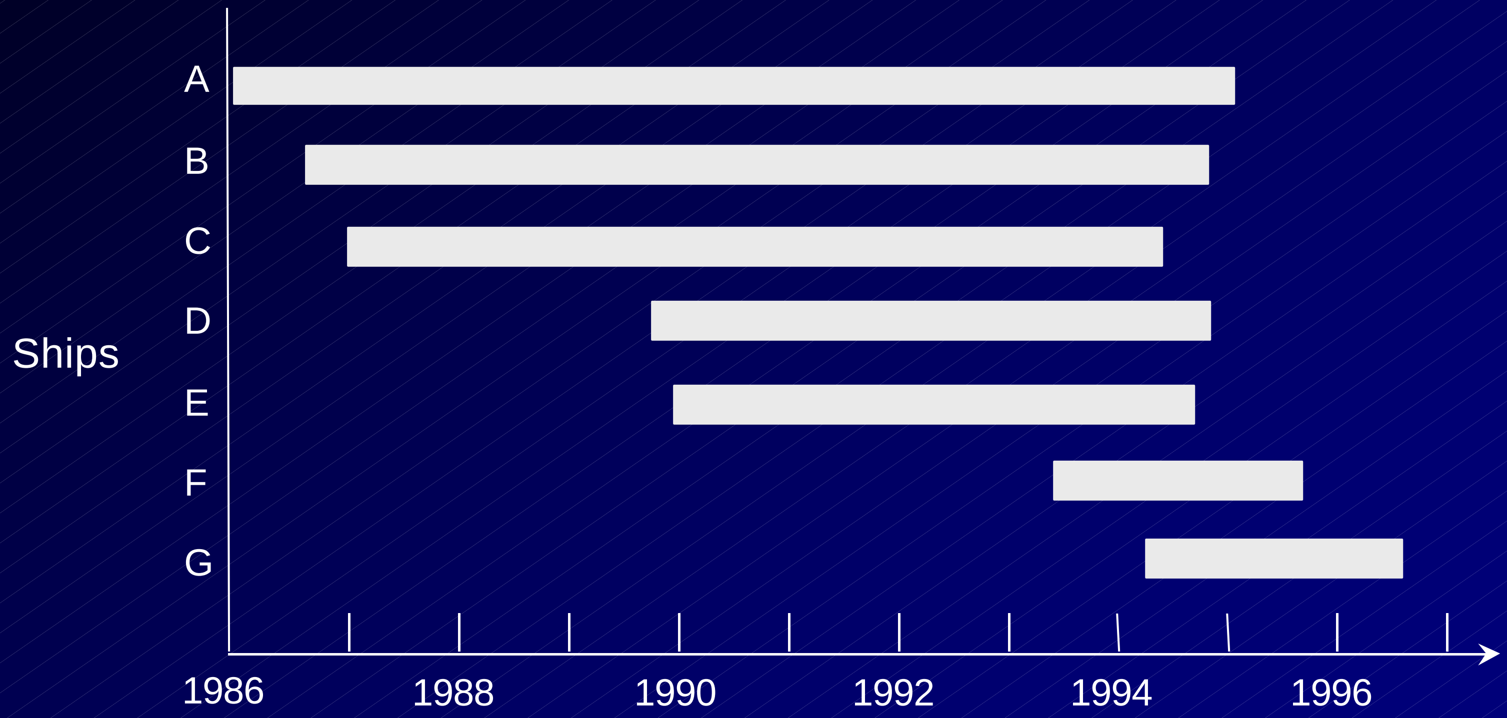
1-1.5 million Ada SLOC

Members of SS2000 Product Family

Over 55 variants

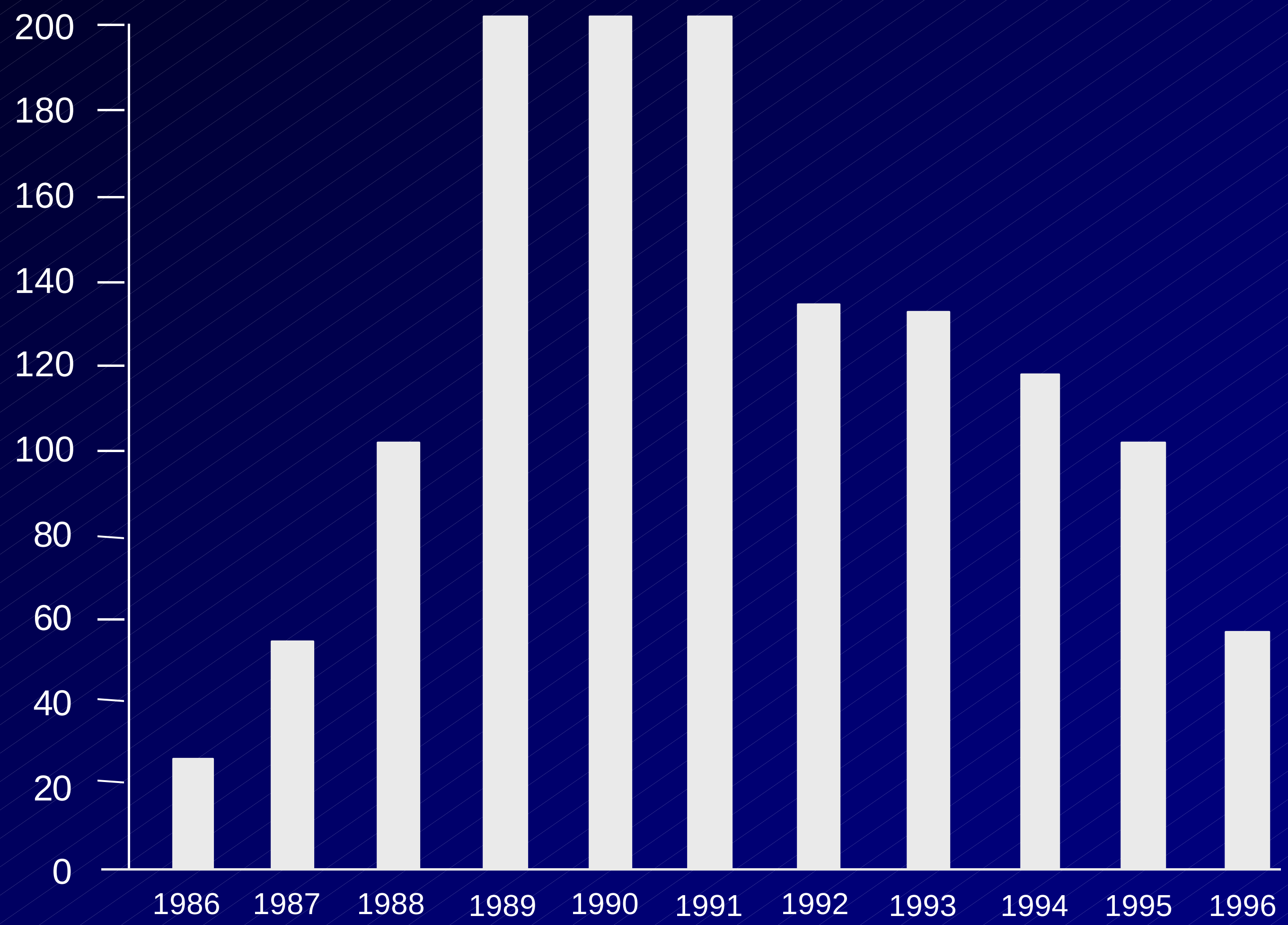
- **Swedish Goteborg class Coastal Corvettes (KKV) (380 tons)**
- **Danish SF300 class multi-role patrol vessels (300 tons)**
- **Finnish Rauma class Fast Attack Craft (FAC) (200 tons)**
- **Australian/New Zealand ANZAC frigates (3225 tons)**
- **Danish Thetis class Ocean Patrol vessels (2700 tons)**
- **Swedish Gotland class A19 submarines (1330 tons)**
- **Pakistani Type 21 class frigates**
- **Republic of Oman patrol vessels**
- **Danish Niels Juel class corvettes**

Result of Changes: Shrinking, Predictable Schedules

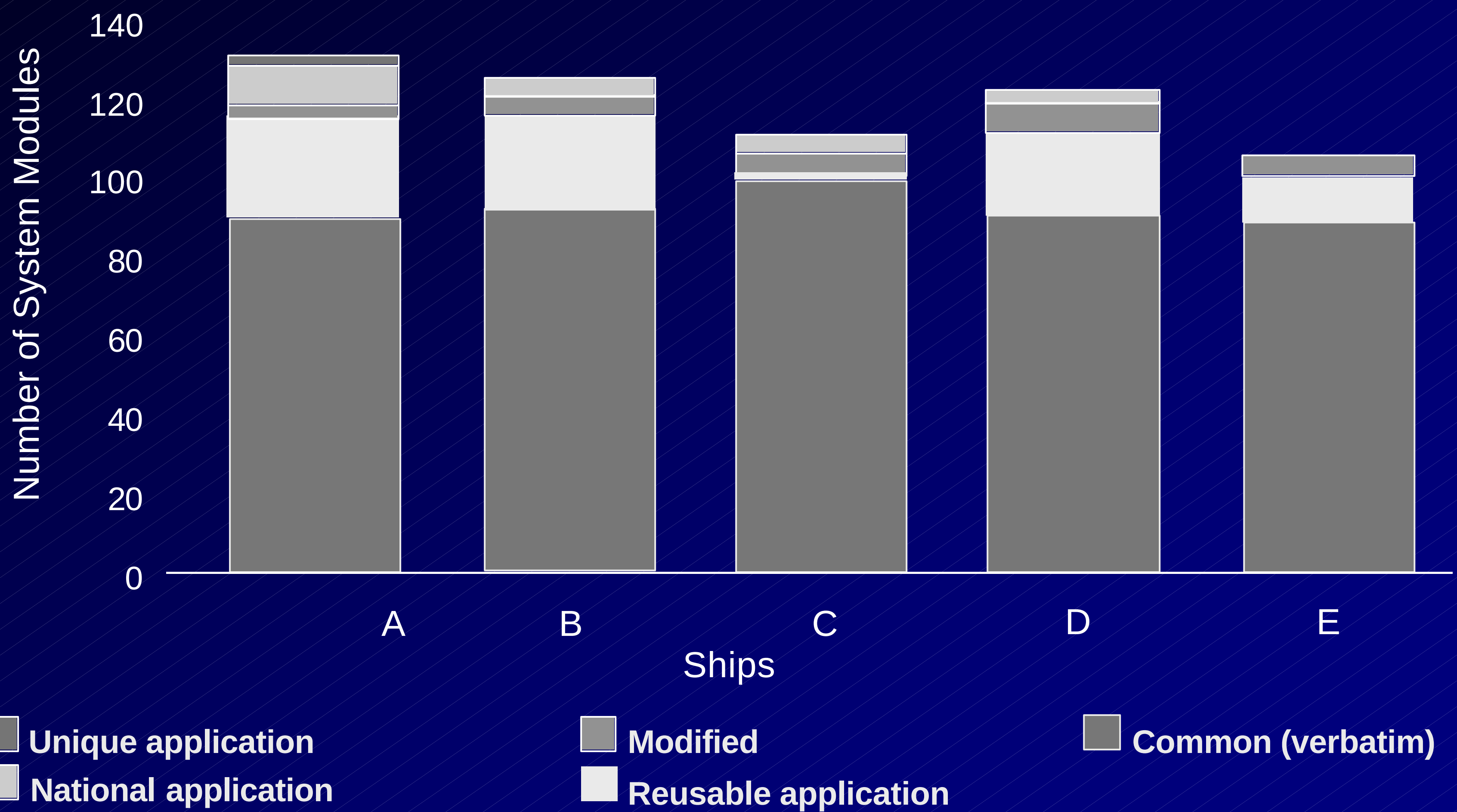


Hardware-to-software cost ratio changed from 35:65 to 80:20

Result of Changes: Lower Staffing

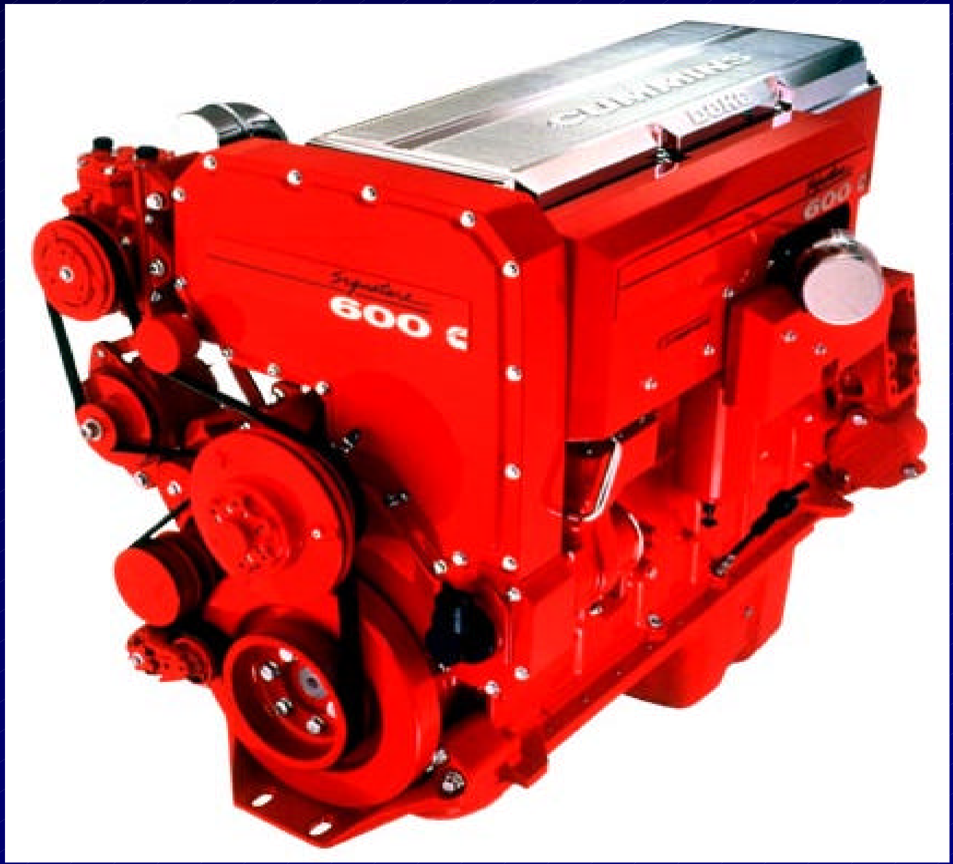


Result of Changes: Reuse



Cummins, Inc.

World's largest manufacturer of large diesel engines.



Complex domain of variation

Today’s diesel engines are driven by software

- Micro-control of ignition timing to achieve optimum mix of power, economy, emissions
- Conditions change dynamically as function of road incline, temperature, load, etc.
- Must also respond to statutory regulations that often change
- Reliability is critical! Multi-million dollar fleets can be put out of commission by a single bug
- 130KSLOC -- C, assembler, microcode
- Different sensors, platforms, requirements

In 1993, Cummins had a problem

Six engine projects were underway
Another 12 were planned.

Each project had complete control over its development process, architecture, even choice of language. Two were trying to use O-O methods.

Ron Temple (VP in charge) realized that he would need another 40 engineers to handle the new projects -- out of the question.

This was no way to do business.

What Cummins did

In May, 1994 Temple halted all the projects.

He split the leading project.

- One half built core assets -- generic software, documentation, and other assets that every product could use
- Other half became pilot project for using the core assets to turn out a product

In 1995, the product was launched on time (relative to re-vamped schedule) with high quality.

Others followed.

Cummins' results

Achieved a product family capability with a breathtaking capacity for variation, or customization

- **9 basic engine types**
- **4-18 cylinders**
- **3.9 - 164 liter displacement**
- **12 kinds of electronic control modules**
- **5 kinds of microprocessors**
- **10 kinds of fuel systems**
- **diesel fuel or natural gas**

Highly parameterized code. 300 parameters are available for setting by the customer after delivery.

Cummins' results by the numbers -1

- 20 product groups launched, which account for over 1000 separate engine applications
- 75% of all software, on average, comes from core assets
- Product cycle time has plummeted. Time to first engine start went from 250 person-months to a few person-months. One prototype was bulit over a weekend.
- Software quality is at an all-time high, which Cummins attributes to product line approach.

Cummins’ results by the numbers -2

- Customer satisfaction is high. Productivity gains enables new features to be developed (more than 200 to date)
- Projects are more successful. Before product line approach, 3 of 10 were on track, 4 were failing, and 3 were on the edge. Now, 15 of 15 are on track.
- Widespread feeling that developers are more portable, and hence more valuable.

Cummins' results by the numbers -3

Supported Components	1992	1993	1994	1995	1996	1997	1998
Electronic control modules (ECMs)	3	3	4	5	5	11	12
Fuel systems	2	2	3	5	5	10	11
Engines	3	3	5	5	12	16	17
Features * ECM	60	80	180	370	1100	2200	2400

Achieving this flexibility without the product line approach would have required 3.6 times the staff Cummins has.

Cummins' results by the numbers -4

Cummins management has a history of embracing change, but carefully targeted change.

They esimate that process improvement alone has brought a benefit/cost ration of 2:1 to 3:1.

They estimate that the product line approach has brought a benefit/cost ration of 10:1.

Product line approach let them quickly enter and then dominate the *industrial* diesel engine market.

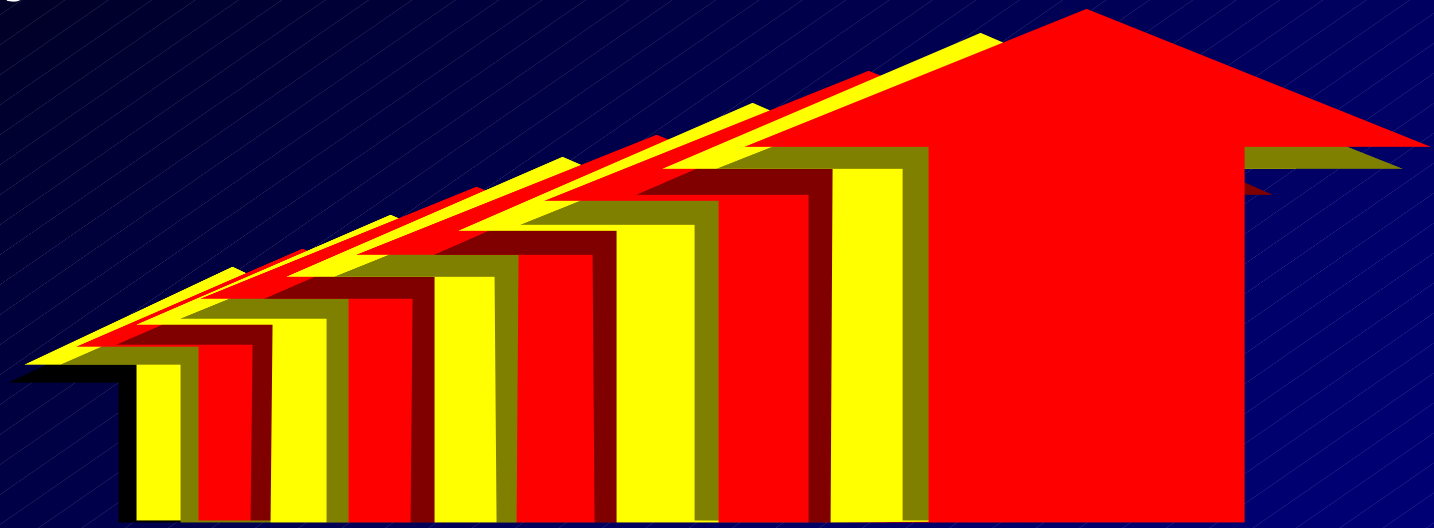
Two companies, same goals

- High quality
- Quick time to market
- Effective use of limited resources
- Product alignment
- Low cost production
- Low cost maintenance
- Mass customization

→ **Improved efficiency and productivity**

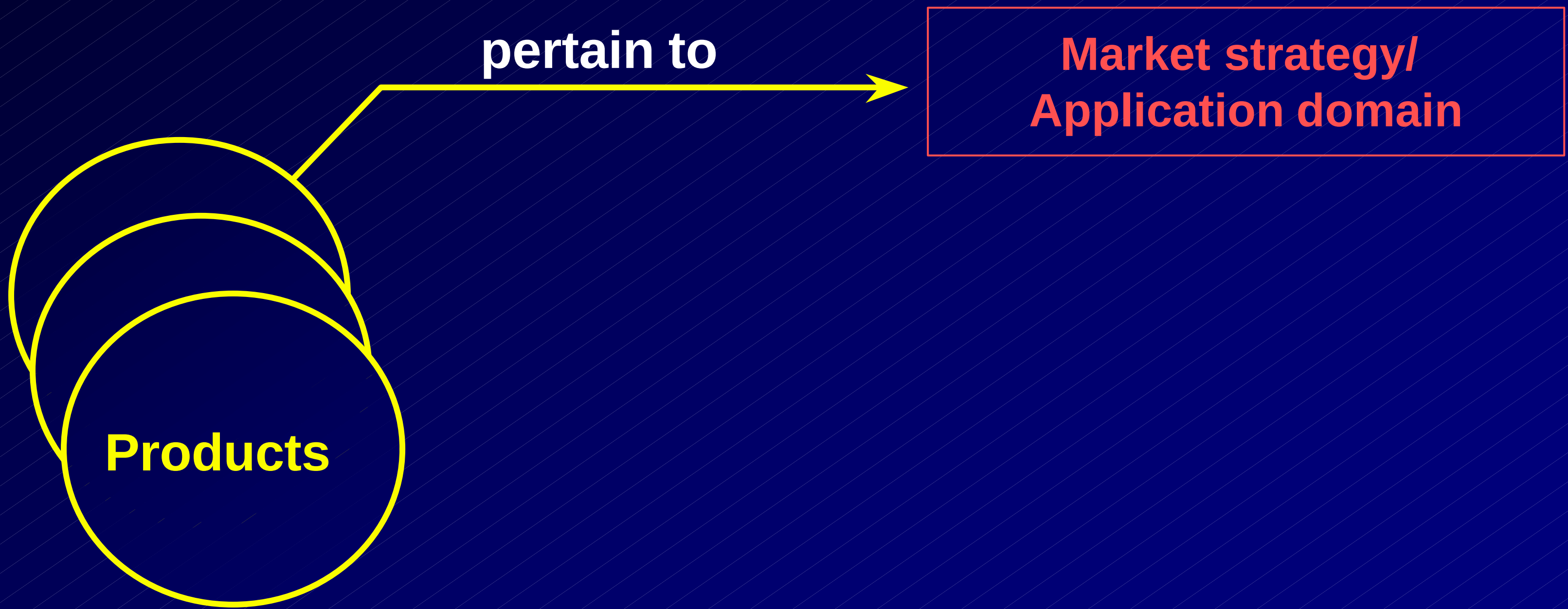
How? Strategic reuse.

Reuse History: From Ad-Hoc to Systematic



What Is a Product Line?

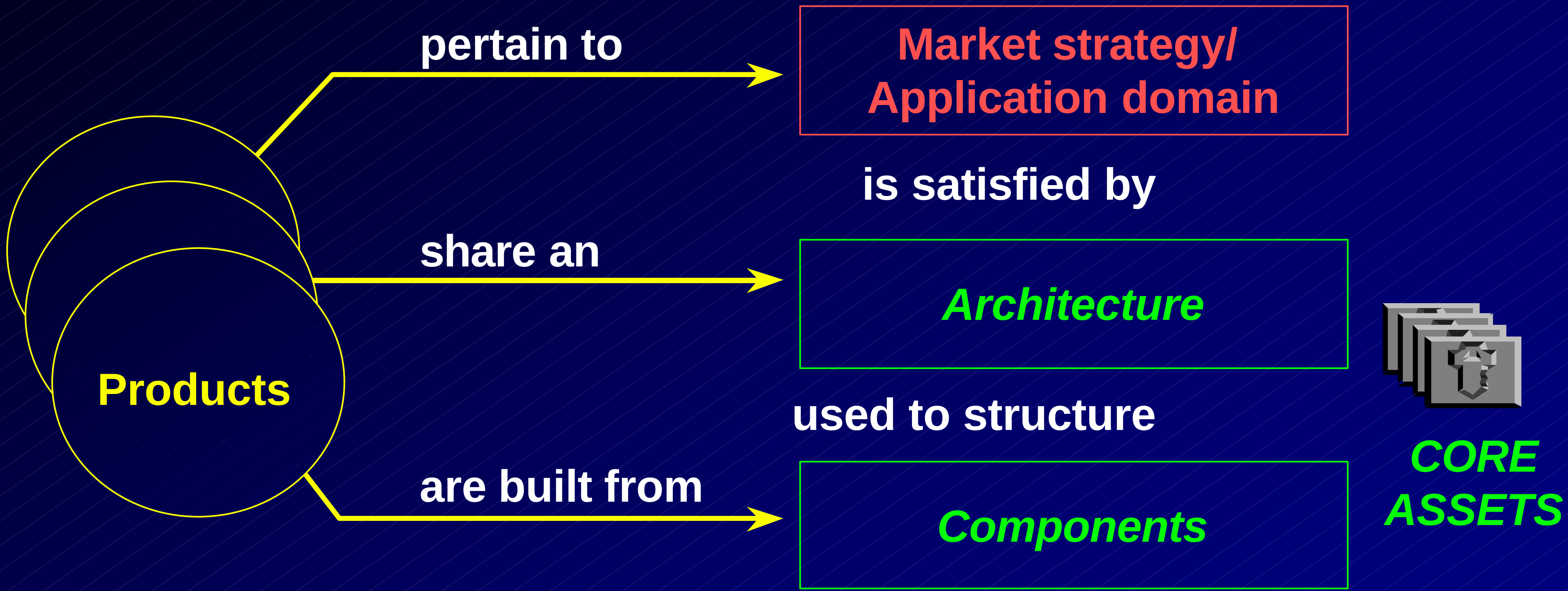
A product line is a group of products sharing a common, managed set of features that satisfy specific needs of a selected market or mission.



What is a Software Product Line?

A software product line is a set of software-intensive systems sharing a common, managed set of features that satisfy the specific needs of a particular market segment or mission and that are developed from a common set of core assets in a prescribed way.

Software Product Lines

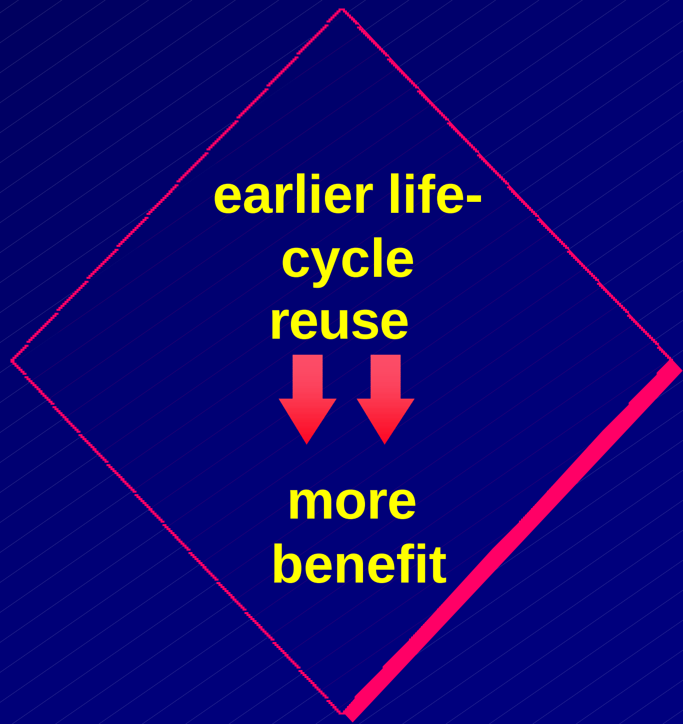


Product lines
- take economic advantage of commonality
- bound variability

How Do Product Lines Help?

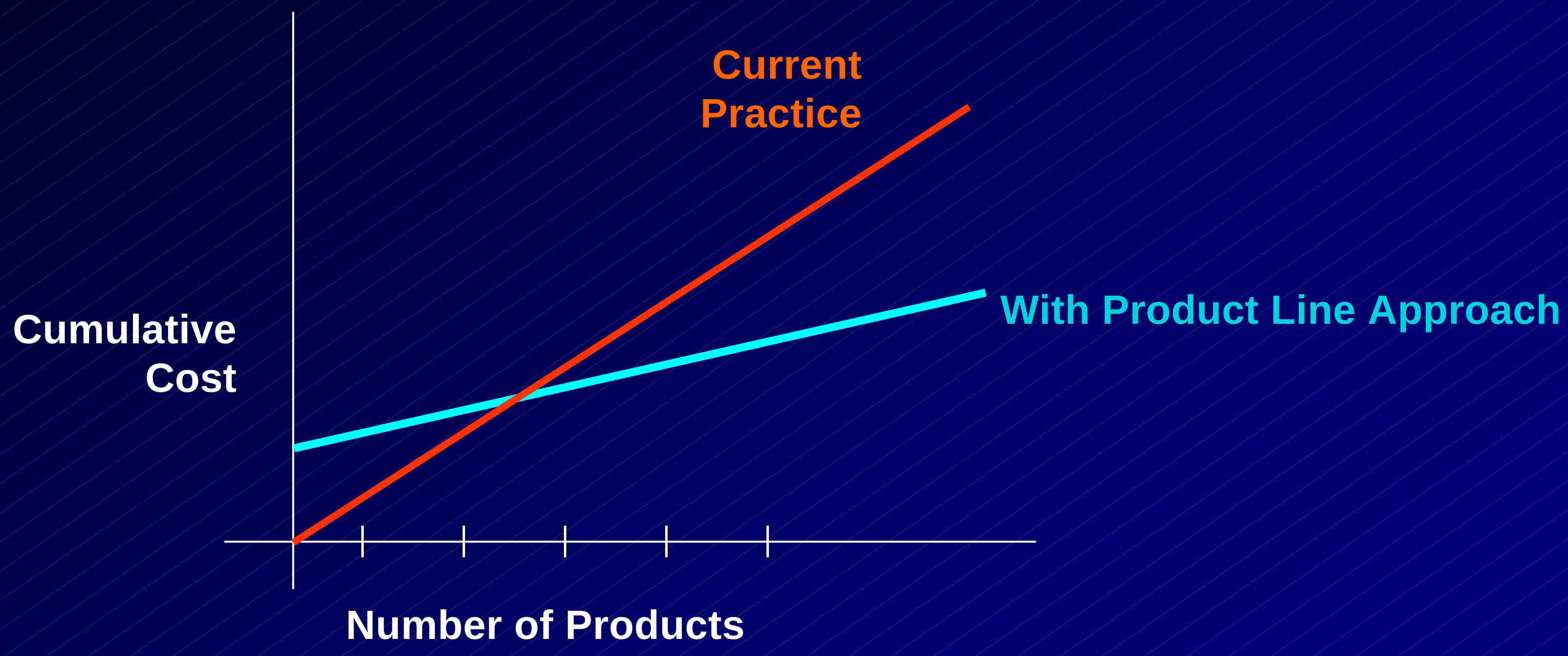
Product lines amortize the investment in these and other *core assets*:

- **requirements and requirements analysis**
- **domain model**
- **software architecture and design**
- **performance engineering**
- **documentation**
- **test plans, test cases, and data**
- **people: their knowledge and skills**
- **processes, methods, and tools**
- **budgets, schedules, and work plans**
- **components**



product lines = strategic reuse

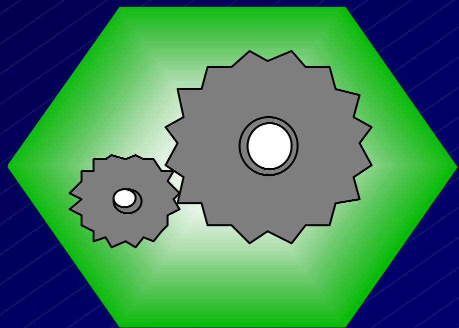
Economics of Product Lines

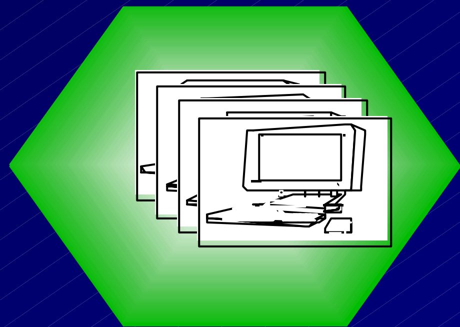


Derived from data supplied by
Lucent Technologies
Bell Laboratories Innovations

The Key Concepts

Use of a common asset base *in production* **of a related set of products**





Architecture

Production Plan

Scope Definition
Business Case

Organizational Benefits

Improved productivity

by as much as 10x

Decreased time to market (to field, to launch...)

by as much as an order of magnitude

Decreased cost

by as much as 60%

Decreased labor needs

by as much as 10X fewer software developers

Increased quality

by as much as 10X fewer defects

Product Line Practice

Contexts for product lines vary widely

- nature of products
- nature of market or mission
- business goals
- organizational infrastructure
- workforce distribution
- process maturity
- artifact maturity

But there are universal essential elements and practices.

CelsiusTech and Cummins both learned vital lessons

Lessons in software engineering

- architectures for product lines
- testing variable architectures and components
- importance of having and capturing domain knowledge
- managing variations
- important of large, pre-integrated chunks

Lessons in technical/project management

- importance of configuration management, and why it’s harder for product lines
- product line scoping: What’s in? What’s out?
- Tool support for product lines

Lessons in organizational management.

- People issues: how to bring about change, how to launch the effort
- Organizational structure: Who builds the core assets?
- Funding: How are the core assets paid for?
- Interacting with the customer has whole new dimension

Embodying the knowledge: SEI Product Line Practice Framework

Web-based, evolving document

Describes product line essential activities

- **Core asset development**
- **Product development**
- **Management**

Describes essential and proven product line practices in the areas of

- **software engineering**
- **technical management**
- **organizational management**

Framework Goals

Identify the foundational concepts underlying the software product lines and the essential issues to consider before fielding a product line.

Identify practice areas that an organization creating or acquiring software product lines must master.

Define practices in each practice area where current knowledge is sufficient to do so.

Provide guidance to an organization about how to move to a product line approach for software.

SEI Information Sources

Case studies, experience reports, and pilots

Workshops

Surveys

Collaborations with customers on actual product lines

Practice Areas

A practice area is a body of work or a collection of activities that an organization must master to successfully carry out the essential work of a product line.

- **Are finer chunks than the essential activities**
- **Must be mastered to carry out the essential activities**
- **Provide starting points for organizations wanting to make and measure product line progress**

Software Engineering Practice Areas

Architecture Definition

Architecture Evaluation

Component Development

COTS Utilization

Mining Existing Assets

Requirements Engineering

Software System Integration

Testing

Understanding Relevant Domains

Technical Management Practice Areas

Configuration Management

Data Collection, Metrics, and Tracking

Make/Buy/Mine/Commission Analysis

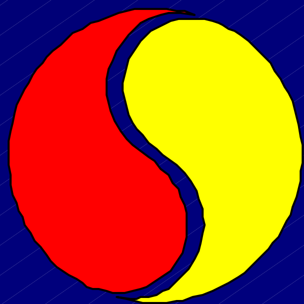
Process Definition

Product Line Scoping

Technical Planning

Technical Risk Management

Tool Support



Organizational Management Practice Areas

Achieving the Right Organizational Structure

Building and Communicating a Business Case

Customer Interface Management

Developing and Implementing an Acquisition Strategy

Funding

Launching and Institutionalizing a Product Line

Market Analysis

Operations

Organizational Planning

Organizational Risk Management

Technology Forecasting

Training

Examples of Product Line Practice - 1

Motorola - FLEXworks Project (family of one-way pagers)

- 4x cycle time improvement
- 80% reuse

Nokia - mobile phones

- went from 4 different phones produced per year to 50 per year

National Reconnaissance Office's Control Channel Toolkit - ground-based satellite systems

- first family member required 1/10 normal number of developers

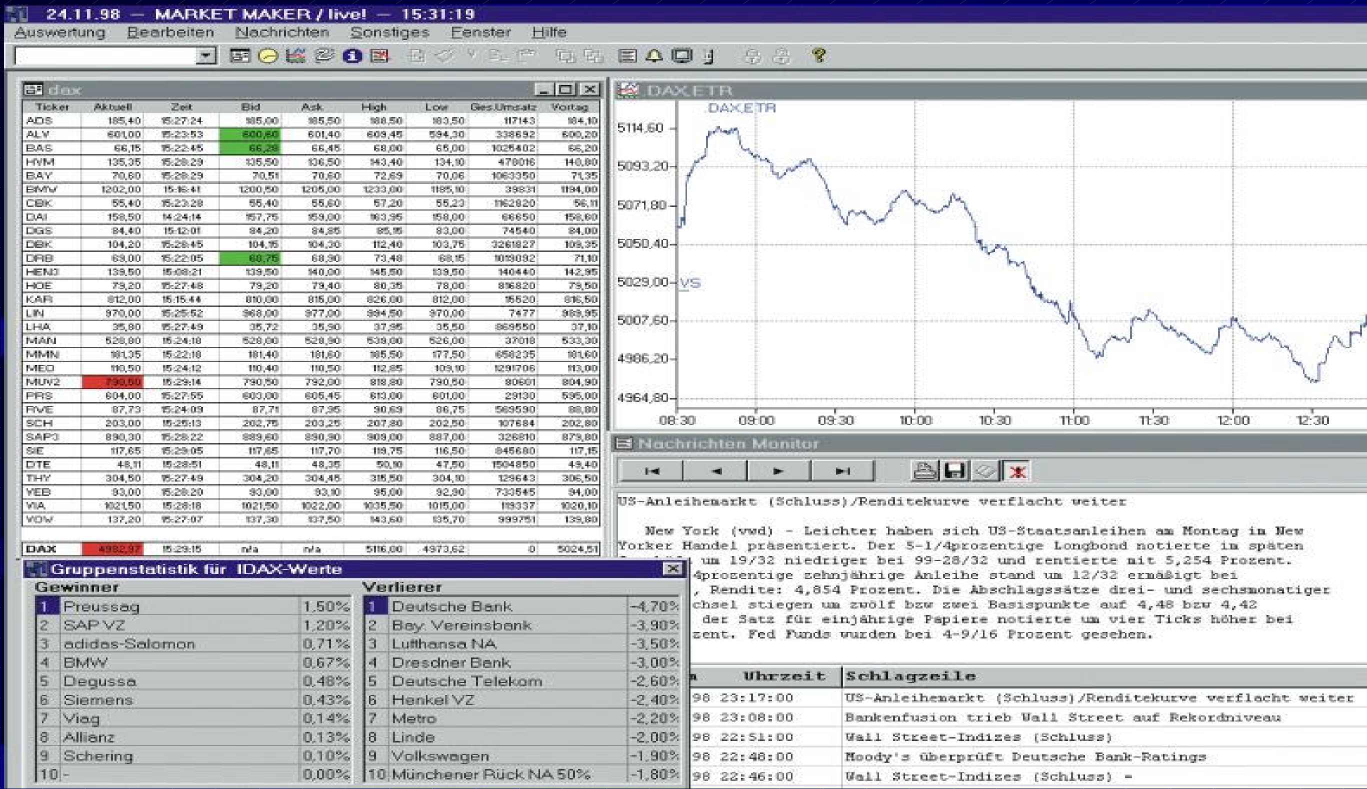
Hewlett Packard - printer systems

- 2-7x cycle time improvement (some 10x)
- Sample Project
  - –shipped 5x number of products
  - –that were 4x as complex
  - –and had 3x the number of features
  - –with 4x products shipped/person

Examples of Product Line Practice - 3

MarketMaker Software AG - German financial info provider

- **able to field a customer-specific solution in about a week**
- **small company (under 50 people)**



Adoption strategies

Proactive (predictive)

- Look ahead, define the product line's scope proactively
- Learn all you can from domain analysis
- Product line adoption is an organization-wide affair
- Cummins and CelsiusTech both took this approach

Reactive

- Start with 1-2 products
- React to new customers as they arrive

Extractive

- Extract commonality from existing products
- Form common asset base from what you already have
- Product line adoption can start in small pockets, spread as acceptance grows

For Additional Information on SEI's Product Line Systems Program

Dave White
Business Development
Product Line Systems Program
Telephone: 412-268-4796
Email: dwhite@sei.cmu.edu

Linda Northrop
Director
Product Line Systems Program
Telephone: 412-268-7638
Email: lmn@sei.cmu.edu

For questions about this talk:
Paul Clements
Product Line Systems Program
Email: clements@sei.smu.edu

U.S. mail:
Software Engineering Institute
Carnegie Mellon University
Pittsburgh, PA 15213-3890

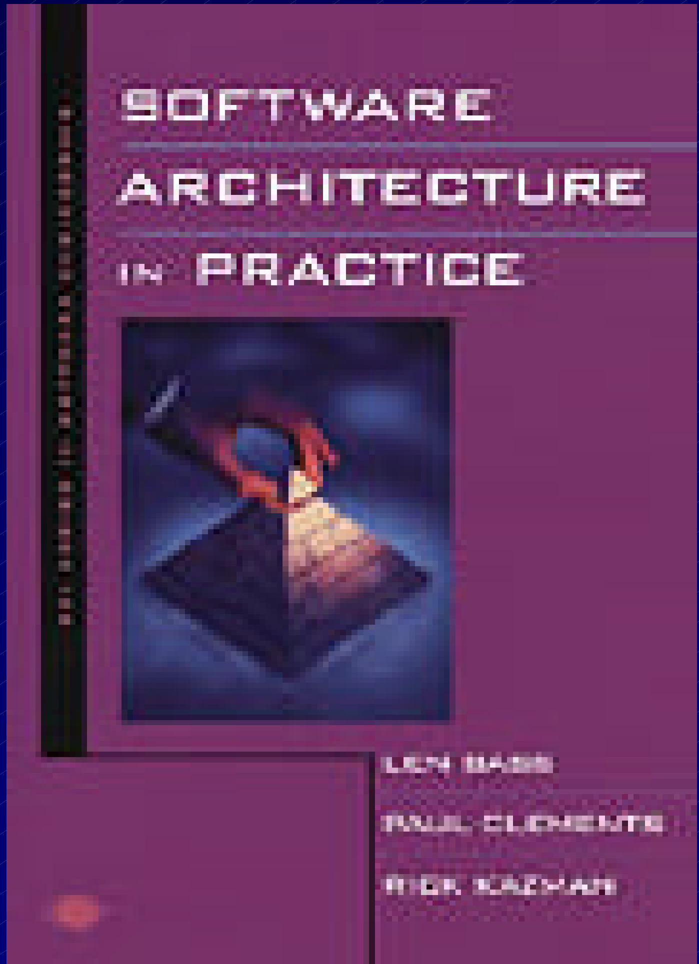
World Wide Web:
http://www.sei.cmu.edu/plp

SEI Fax: 412-268-5758

To read more about CelsiusTech

Software Architecture in Practice
Len Bass
Paul Clements
Rick Kazman
Addison Wesley 1998

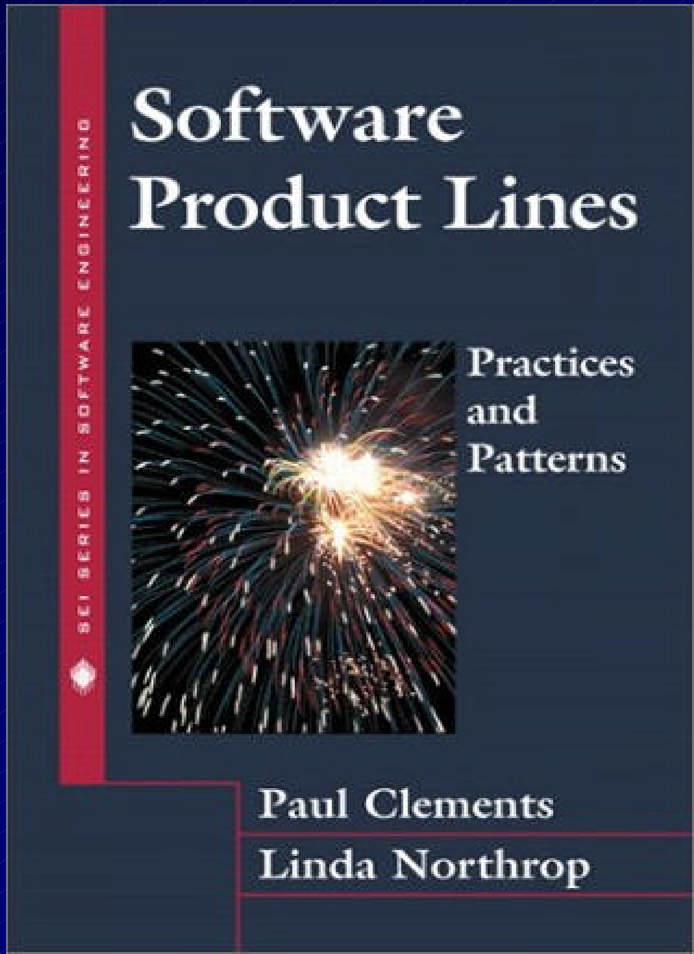
- **Seven case studies in successful software architectures**
- **Architecture evaluation**
- **Architecture business cycle**
- **Achievement of system qualities through architecture**



To read more about Cummins

Software Product Lines:
Practices and Patterns
Paul Clements
Linda Northrop
Addison Wesley 2001
~600 pages

- Product line fundamentals and economics
- Practice areas described
- Patterns for adoption
- 3 Detailed case studies
- Product Line Technical Probe



Schedule and Outline

0900 - 0915 Introductions
0915 - 0945 The Architecture Business Cycle
0945 -1000 What is architecture?
1000 - 1030 Why is architecture important?
1030 - 1045 Break
1045 - 1115 Architectural structures
1115 - 1200 New developments in software architecture
- Software product lines
- **Aspect-oriented software development**
- Predictable assembly from certifiable components

Aspect-Oriented Software Development (AOSD)

Also called "multi-dimensional separation of concerns." Recognition that separation of concerns may be performed in many ways.

Example:

- **Dividing a system into elements based on likely application-based changes**
- **Each element still must reflect**
  - **a particular error-handling philosophy**
  - **an architectural packaging decision**
  - **naming conventions**
  - **interaction protocols**
  - **…and many others**

AOSD (cont'd.)

AOSD tools and languages let programmers *weave* these separate concerns together in discrete elements, so that these global design decisions (that have far-reaching effects) can be changed locally.

AOSD represents the introduction of truly architectural thinking into program development.

For more information: http://www.aosd.net.

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Predictable Assembly of Certifiable Components (PACC)

At the vanguard of work on component-based systems.

Previous work has concentrated on component selection and qualification, and building frameworks for component-based systems.

This work focuses on building systems with provable quality attributes from components.

PACC -2

Two driving questions:

- **Given a set of components with certified quality attributes, what can you conclude about the qualities of a system including those component?**
- **Given a quality attribute need for a system, what must you be able to certify about its components to know you've satisfied that need?**

Very early work. Preliminary results with latency, starting to work on reliability.

For more information:

http://www.sei.cmu.edu/pacc/index.html