CSE403: Software Engineering

David Notkin
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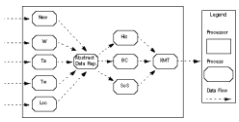
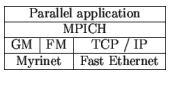
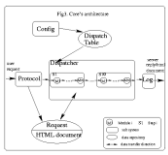
Software architecture

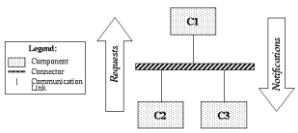
- An area of significant attention in the last decade or so
  - D. Garlan and M. Shaw. An Introduction to Software Architecture. In V. Ambriola and G. Tortora (ed.), *Advances in Software Engineering and Knowledge Engineering* (1993).
  - D.E. Perry and A.L. Wolf. Foundations for the Study of Software Architecture. *ACM SIGSOFT Software Engineering Notes 17*, 4 (Oct 1992).
- There are two basic goals (in my opinion)
  - Capturing, cataloguing and exploiting experience in software designs
  - Allowing reasoning about classes of designs

Box-and-arrow diagrams:
taken from the web without attribution









These diagrams

- Clearly, these diagrams give value
  - You can find them all over the web, in textbooks, in technical documents, in research papers, over whiteboards in your office, on napkins in the cafeteria, etc.
- At the same time, they are generally ill-defined: what does a box represent? an arrow? a layer? adjacent boxes? etc.
- One view of software architecture research is to determine ways to give these diagrams clearer semantics and thus additional value

An aside: compilers I

- The first compilers had *ad hoc* designs
- Over time, as a number of compilers were built, the designs became more structured
  - Experience yielded benefits
    - Compiler phases, symbol table, etc.
  - Plenty of theoretical advances
    - Finite state machines, parsing, ...

An aside: compilers II

- Compilers are perhaps the best example of shared experience in design
  - Lots of tools that capture common aspects
  - Undergraduate courses build compilers
  - Most compilers look pretty similar in structure
- But we still don't fully generate compilers
  - Despite lots of effort and lots of money
  - In any case, the code in compilers is often less clean than the designs
- Despite this, the perception of a shared design gives leverage
  - Communication among programmers
  - Selected deviations can be explained more concisely and with clearer reasoning

Other domains?

- Which other domains are as successful in this regard as compilers?
- Quite a few, but generally much more narrow
  - DARPA ran a large project, Domain-Specific Software Architectures (DSSA) a few years ago
    - ISI: Command and control message processing
    - Honeywell: Guidance, navigation and control
    - …
  - Some 4GL approaches are basically domain-specific systems
- Essentially: (Parnas) program families in which systems have "so much in common that it pays to study their common aspects before looking at the aspects that differentiate them"
  - The OS example has not really come to fruition

Back to software architecture

- One hope is that by studying our experiences with a variety of systems, we can gain leverage as we did with compilers
- Capture the strengths and weaknesses of various software structures
  - Perhaps enabling designers to select appropriate architectures more effectively
- Benefit from high-level study of software structure

Another motivation: architectural mismatch

- Garlan, Allen, Ockerbloom tried to build a toolset to support software architecture definition from existing components
  - OODB (OBST)
  - graphical user interface toolkit (Interviews)
  - RPC mechanism (MIG/Mach RPC)
  - Event-based tool integration mechanism (Softbench)
- It went to hell in a handbasket, not because the pieces didn't work, but because they didn't fit together
- Architectural Mismatch: Why Reuse Is So Hard. *IEEE Software 12*, 6 (Nov. 1995).

Mismatches included

- Excessive code size
- Poor performance
- Needed to modify out-of-the-box components (e.g., memory allocation)
- Error-prone construction process
- …

So what?

- The claim is that many of the problems were of an architectural nature
  - What assumptions are made, need they be made, etc.?
- With some forethought, many of these mismatches could, in principle, be avoided

Some classic definitions:

http://www.sei.cmu.edu/architecture/definitions.html

- …architecture is concerned with the selection of architectural elements, their interactions, and the constraints on those elements and the interactions necessary to provide a framework in which to satisfy the requirements and serve as a basis for the design [Perry and Wolf].
- An architecture is the set of significant decisions about the organization of a software system, the selection of the structural elements and their interfaces by which the system is composed, together with their behavior as specified in the collaborations among those elements, the composition of these structural and behavioral elements into progressively larger subsystems, and the architectural style that guides this organization---these elements and their interfaces, their collaborations, and their composition [Booch, Rumbaugh, and Jacobson, 1999]

More definitions

- ...beyond the algorithms and data structures of the computation; designing and specifying the overall system structure emerges as a new kind of problem. Structural issues include gross organization and global control structure; protocols for communication, synchronization, and data access; assignment of functionality to design elements; physical distribution; composition of design elements; scaling and performance; and selection among design alternatives [Garlan and Shaw].
- The structure of the components of a program/system, their interrelationships, and principles and guidelines governing their design and evolution over time [Garlan and Perry].
- ...an abstract system specification consisting primarily of functional components described in terms of their behaviors and interfaces and component-component interconnections [Hayes-Roth].

Components and connectors

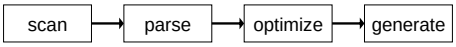
- (Most people now agree that) software architectures includes *components* and *connectors*
- *Components* define the basic computations comprising the system: abstract data types, filters, etc.
- *Connectors* define the interconnections between components: procedure call, event announcement, asynchronous message sends, etc.
- The line between them may be fuzzy at times
  - Ex: A connector might (de)serialize data, but can it perform other, richer computations?

Architectural style

- Defines the vocabulary of components and connectors for a family (style)
- Constraints on the elements and their combination
  - Topological constraints (no cycles, register/announce relationships, etc.)
  - Execution constraints (timing, etc.)
- By choosing a style, one gets all the known properties of that style (for any architecture in that style)
- These properties can be quite broad
  - Ex: performance, lack of deadlock, ease of making particular classes of changes, etc.

Not just boxes and arrows

- Consider pipes & filters, for example (Garlan and Shaw)
  - Pipes must compute local transformations
  - Filters must not share state with other filters
  - There must be no cycles
- If these constraints are not satisfied, it's not a pipe & filter system
  - One can't tell this from a picture
  - One can formalize these constraints



WRIGHT

- WRIGHT provides a formal basis for architectural description (ADL = architectural description language)
- Language for precisely defining an architectural specification, as a basis for analyzing the architecture of individual software systems and families of systems
- Underlying model in CSP (communicating sequential process, Hoare), checkable using standard model checking technology
  - Defines a set of standard consistency and completeness checks

Defining a connector in WRIGHT: client-server

```
connector C-S-connector =

   role Client = (request!x → result?y → Client) ∏ §

   role Server = (invoke?x → return!y → Server) □ §

   glue = (Client.request?x → Service.invoke!x →
           Service.return?y → Client.result!y → glue)
□ §
```

Pipe connector in WRIGHT

```
Connector Pipe =
   role Write = write → Writer ∏ close → √
   role Reader =
      let ExitOnly = close → √
      in let DoRead =
           (read → Reader □ read-eof → ExitOnly)
      in DoRead □ ExitOnly
   glue = let ReadOnly =
           Reader.Read → ExitOnly
          Reader.read-eof → Reader.close → √
          Reader.close → √
```

- Ensures (among other things) that there is a way to notify reader than pipe is empty when writer closes the pipe

Decoding a little bit

- Connectors represent links to components on the roles, which are ports of the connectors
  - The WRIGHT process descriptions describe the obligations of each connector
- The glue process coordinates the behavior of the roles
  - Essentially, it defines a high-level protocol
- One can then prove properties about the stated protocols

Benefits

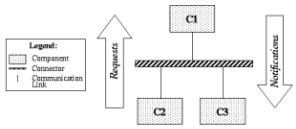
- In the pipes & filters example, the constraints ensure a lack of deadlock
  - In any instantiation of the style that satisfies the constraints
- One can think of the constraints as obligations on the designer and on the implementor
  - Some properties can be automatically checked

Specializations

- Architectural styles can have specializations
  - A pipeline might further constrain an architecture to a linear sequence of filters connected by pipes
  - A pipeline would have all properties that the pipe and filter style has, plus more

C2 Architecture:
UC Irvine (Taylor et al.)

- Based on generalization of a collection of designs of user interface systems
- Informally, a C2 architecture is a network of concurrent components linked together by connectors
- http://www.ics.uci.edu/pub/c2/c2.html



C2 Composition

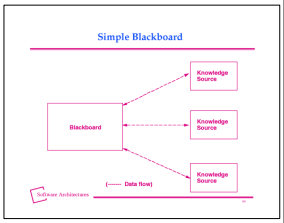
- The top of a component may be connected to the bottom of a single connector
- The bottom of a component may be connected to the top of a single connector
- There is no bound on the number of components or connectors that may be attached to a single connector
- When two connectors are attached to each other, it must be from the bottom of one to the top of the other

C2 Communication

- Solely by exchanging messages
- Each component has a top and bottom domain
  - The top specifies the set of notifications to which a component responds, and the set of requests it emits upwards
  - The bottom specifies the set of notifications that a component emits downwards and the set of requests to which it responds
- Central principle: limited visibility (substrate independence)
  - A component within the hierarchy can only be aware of components "above" it and is completely unaware of the components "beneath" it

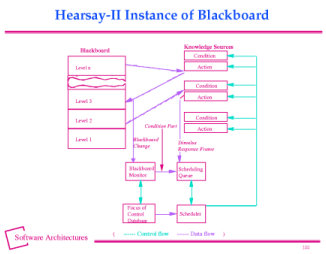
Blackboard architectures

- *The knowledge sources*: separate, independent units of application dependent knowledge. No direct interaction among knowledge sources
- *The blackboard data structure*: problem-solving state data. Knowledge sources make changes to the blackboard that lead incrementally to a solution to the problem.
- *Control*: driven entirely by state of blackboard. Knowledge sources respond opportunistically to changes in the blackboard.



Blackboard systems have traditionally been used for applications requiring complex interpretations of signal processing, such as speech and pattern recognition.

Hearsay-II: blackboard



Well, do they help?

- I like the basic software architecture research as an intellectual tool
  - The work is helping us better understand classes of software structures that have shown themselves as useful
  - Simply improving our shared terminology is a benefit

Open question I

- What properties can be analyzed?
  - WRIGHT
    - Reason about architectures in terms of protocols, using a CSP-like language
    - Roughly, type-checking of architectural styles
  - Of these, which are sufficiently important to justify the investment
    - The investment is high, but in theory amortized
  - What about across heterogeneous architectures?

Open question II

- How does one produce new architectural styles?
- When?

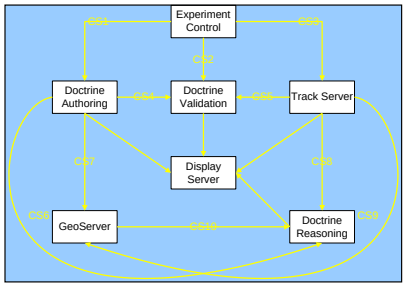
Open question III

- What is the relationship between architectural and implementation?
  - Does architectural information aid in going from design to implementation?
  - What happens as the implementation evolves in ways inconsistent with the architecture?
    - Which properties still hold, and how do we know this?
- ArchJava?

Experience

- It's a hot area, with lots of companies paying attention
- Allen & Garlan reported on a case study in applying architectural modeling to the AEGIS Weapons System
  - Used formalism to help "expose and resolve some of the architectural problems that arose in implementing the system"
- Similar advantages for the HLA project
  - Distributed simulation for the DoD

AEGIS Weapons System:
control of US Navy ships



Example benefits in AEGIS

- Clarifying client-server misconceptions
  - Which party initiated interactions?
  - Re-established after every request?
  - Synchronous or asynchronous?
- WRIGHT used to clarify
  - Avoiding deadlocks
  - Reducing unnecessary synchronization
  - And to simplify instrumentation of the architecture

Forcing discussions

- In some ways, the primary benefit of architecture Garlan is that it forces discussions of some critical issues
  - The Xerox PARC Mesa/Cedar group did roughly the equivalent by spending enormous amounts of times in defining and clarifying interfaces, before coding
- Finding errors earlier is generally considered to be better, of course
- I'm unsure the degree to which the formalism per se helps, although there are surely some supporting examples

Questions?