Lecture 5

Software Architecture

Announcement

- Project proposal was due yesterday.
  - I received your email submission. No worries.
- The project proposal will be graded.
- The next checkpoint (Feb 23rd) for Option A students are ***not mandatory.***

Announcement

- Don’t forget to put a header [EE382V] when emailing me.
- Please cc TA when you send me an email for _all_ your correspondences.

Announcement

- I will select some good student reviews (3pt) and upload them --- of course I will make them anonymous.

Today’s Presentation

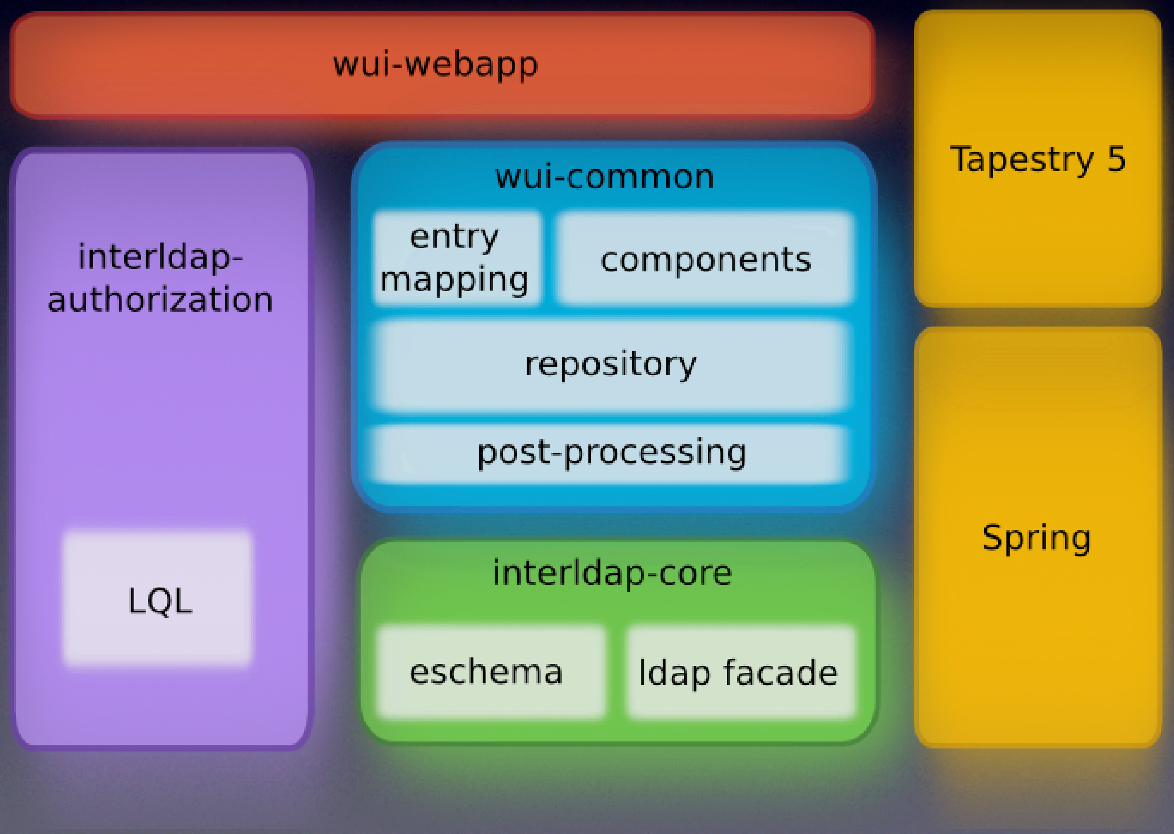
- Advocate: Christopher Spandikow

Today's Lecture on Software Architecture

- We read the software architecture paper by David Garlan and Mary Shaw at CMU.
- Around the same time, Alexander Wolf and Dewayne Perry (back then they were at Bell Lab) also wrote a paper on the idea of software architecture.
- Dr. Perry is an active researcher in Software Architecture and he is here in our department.
- Some of today's slides are borrowed from Rob DeLine at Microsoft Research, who did his Ph.D under the supervision of Mary Shaw at CMU.
- Some of today's slides are borrowed from Vibha Sazawal at UMD, who worked with Jonathan Aldrich at CMU, a creator of ArchJava.

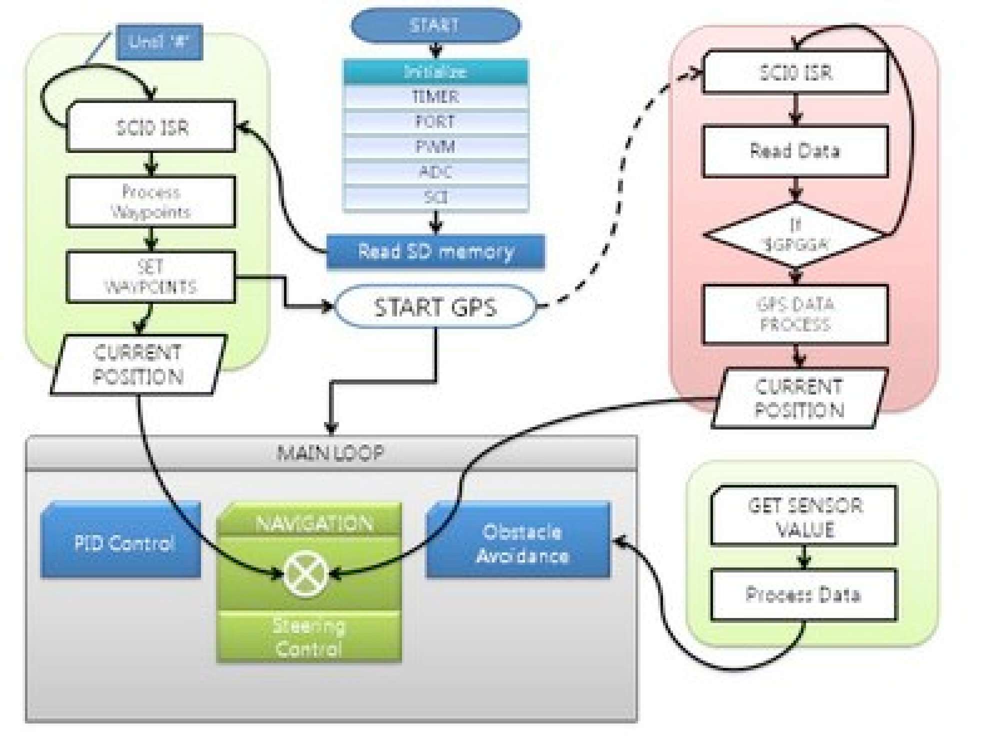
What is a software architecture?

- According to Google Images



What is a software architecture?

- According to Google Images



What is a software architecture?

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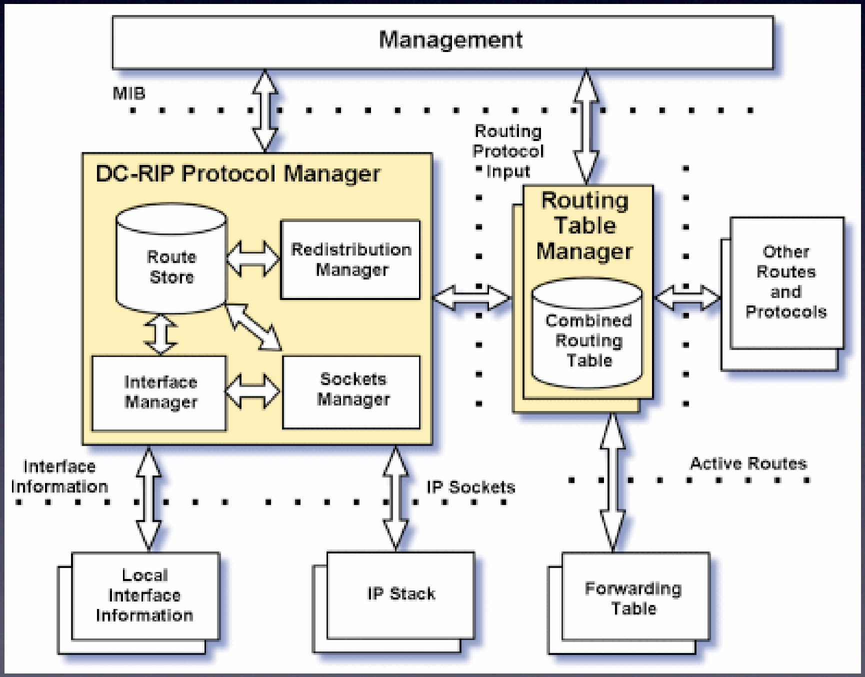


What is software architecture?

- CMU-SEI definition
  - software elements, the externally visible properties of those elements and the relationships among them

What do these figures mean?

- Boxes
- Lines
- Grouping

What do these figures mean?

- Boxes => Component
- Lines => Connections
- Grouping, backgrounds, fences => Composition

Components (boxes)

- Places where computation takes place
- Places where data is stored
- Box shapes distinguish component types

Connections (lines, arrows)

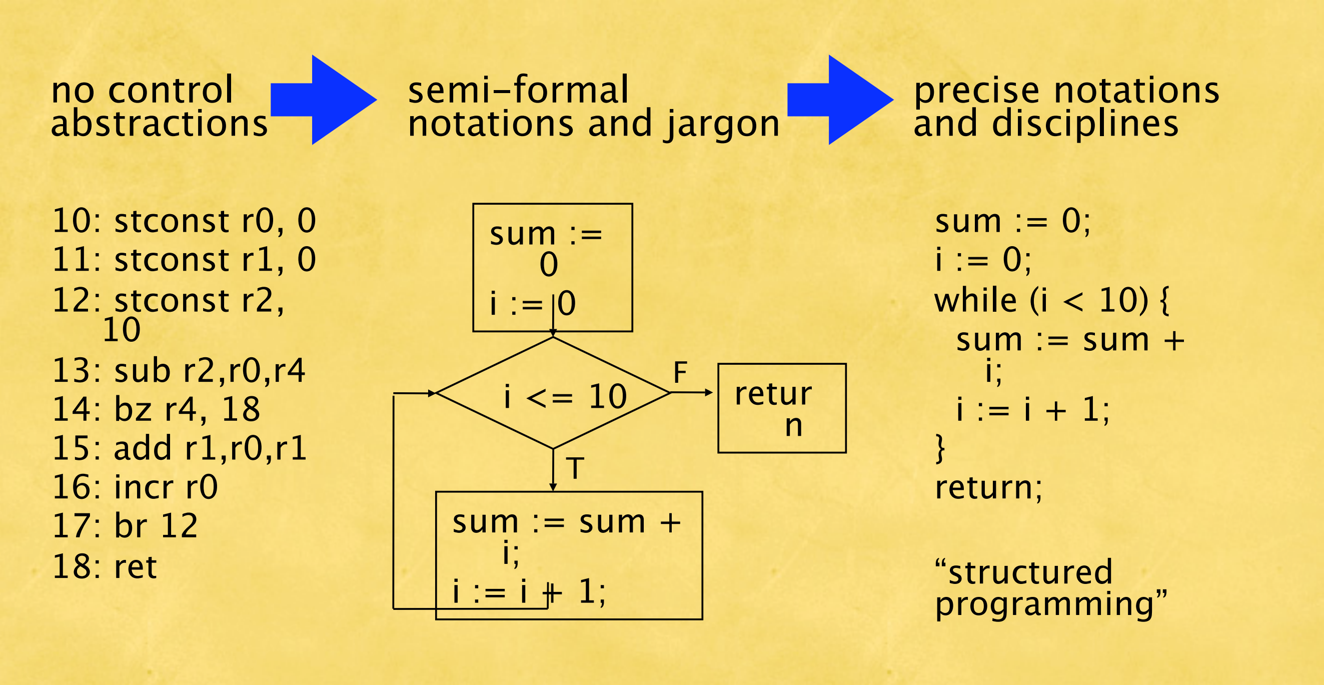
- Some kind of interaction among components
- Often binary, sometimes n-ary
- Line attributes distinguish connection types

Composition (grouping, backgrounds, fences)

- Show commonality and boundaries

Carving out a new level of abstraction

- In the early age of programming languages...



no control abstractions → semi-formal notations and jargon → precise notations and disciplines

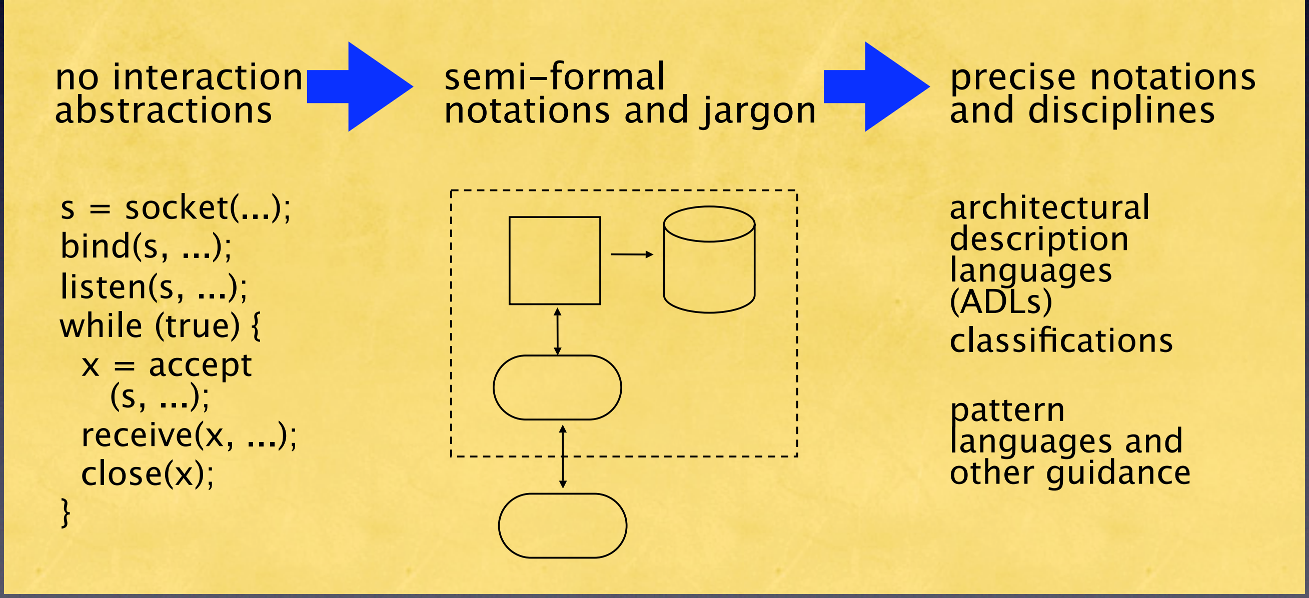
```
10: stconst r0, 0
11: stconst r1, 0
12: stconst r2,
    10
13: sub r2,r0,r4
14: bz r4, 18
15: add r1,r0,r1
16: incr r0
17: br 12
18: ret
```

```
sum := 0;
i := 0;
while (i < 10) {
  sum := sum +
    i;
  i := i + 1;
}
return;
```

“structured programming”

Architecture as a new abstraction

- Researchers are carving out a higher-level abstraction



no interaction abstractions → semi–formal notations and jargon → precise notations and disciplines

```
s = socket(...);
bind(s, ...);
listen(s, ...);
while (true) {
  x = accept
    (s, ...);
  receive(x, ...);
  close(x);
}
```

architectural description languages (ADLs)

classifications

pattern languages and other guidance

What kinds of jargon have you heard of?

- Client / Server?
- Three-tier architecture
- Implicit invocation / event-driven
- Manager and agent
- Pipeline
- Peer to peer
- Model view controller
- Regular programs built in procedural languages

Software Architecture Styles

- Pipe and filter
- Client and server
- Object oriented
- Publish and subscribe
- Layers
- Microkernel
- Web services

Example: Pipe and Filter

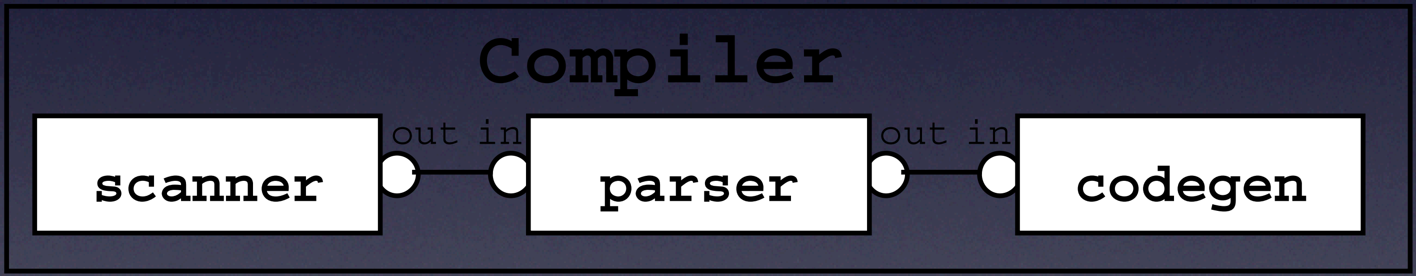
- A filter reads streams of data on its inputs and produces streams of data on its outputs by applying a local transformation.
- Component (Filter)
- Connector (Pipe)
- Constraints
    - filters must be independent => no shared states among filters
    - filters do not know the identity of other filters
    - outputs are the same regardless of ordering of filters

Example: Pipe and Filter

- Advantages:
  - programmers can understand the overall input and output behavior as a simple composition of filters
  - reuse: any two filters can be hooked together
  - different types of filters can be easily added or deleted
- Disadvantages:
  - not good for interactive applications as each filter provides a complete transformation of input data to output data
  - each filter has to parse and unparse the data

Pipe Line Architecture

- a linear sequence of filters
- e.g. a compiler architecture



Example: Event-based, Implicit Invocation

- Instead of invoking a procedure directly, a component can announce or broadcast one or more events.
- Other components in the system can register an interest in an event by associating a procedure with the event.
- e.g. Java Swing GUI
- Component: modules whose interfaces provide both a collection of procedures and a set of events
- Connector: traditional procedure calls as well as bindings between event announcements and procedure calls

Example: Event-based, Implicit Invocation

- Constraints
  - Announcers of events do not know which components will be affected by those events
  - Components cannot make assumptions about order of processing
- Advantages
  - Any components can be introduced into a system by registering for the events
- Disadvantages
  - Component relinquish control over the computation performed by the system
  - Ordering is difficult to understand, difficult to expect when finished
  - Shared event data

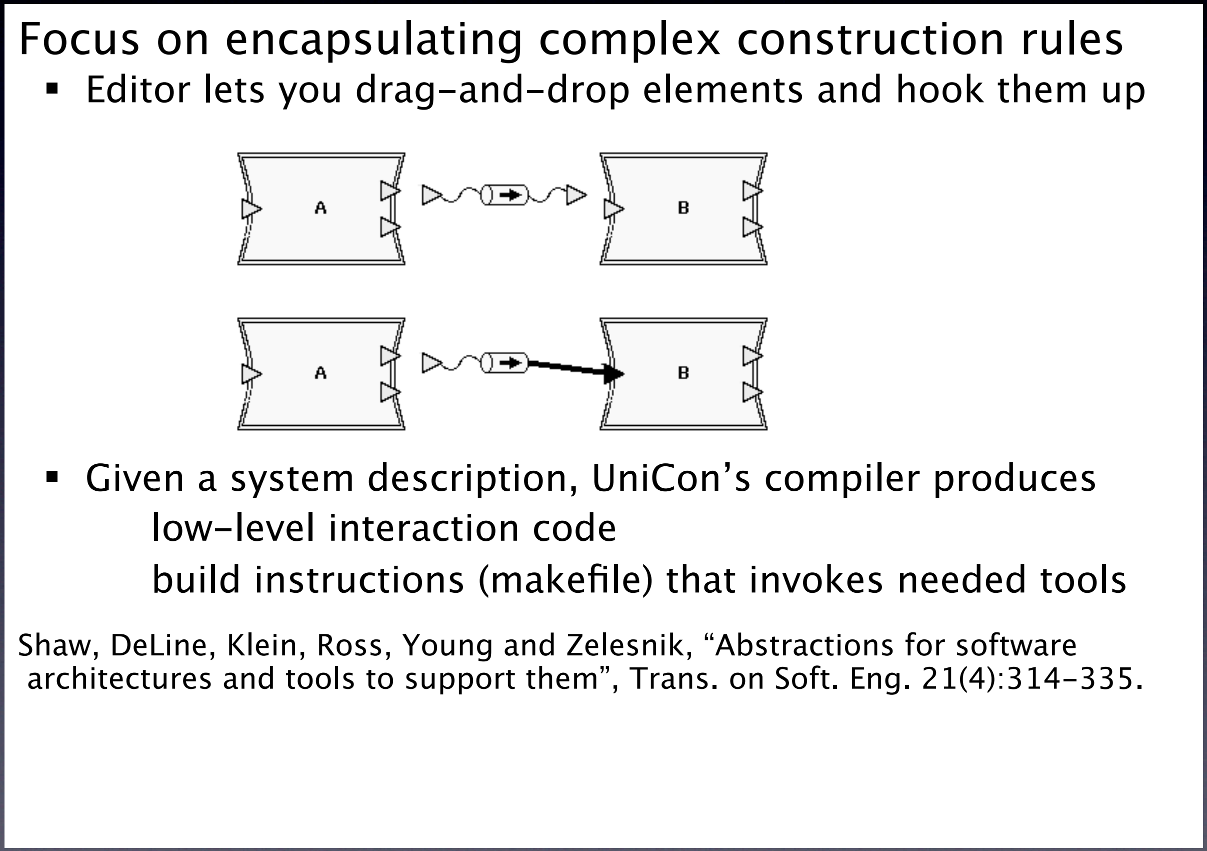
Architecture Description Languages (ADL)

- In the 90s, researchers created many architectural notations.
  - grew out of module interconnection languages (1975)
  - focus on recording system structure (typically static structure)
  - different goals, but many shared concepts

Common Concepts in ADL

- Components (computation)
- Connectors (common disagreement: aren't these just components?)
- Compositions (combinations of elements to form new elements)
- Architectural Styles (constraints on elements and their composition)

UniCon



Focus on encapsulating complex construction rules

- Editor lets you drag-and-drop elements and hook them up

- Given a system description, UniCon's compiler produces
  low-level interaction code
  build instructions (makefile) that invokes needed tools

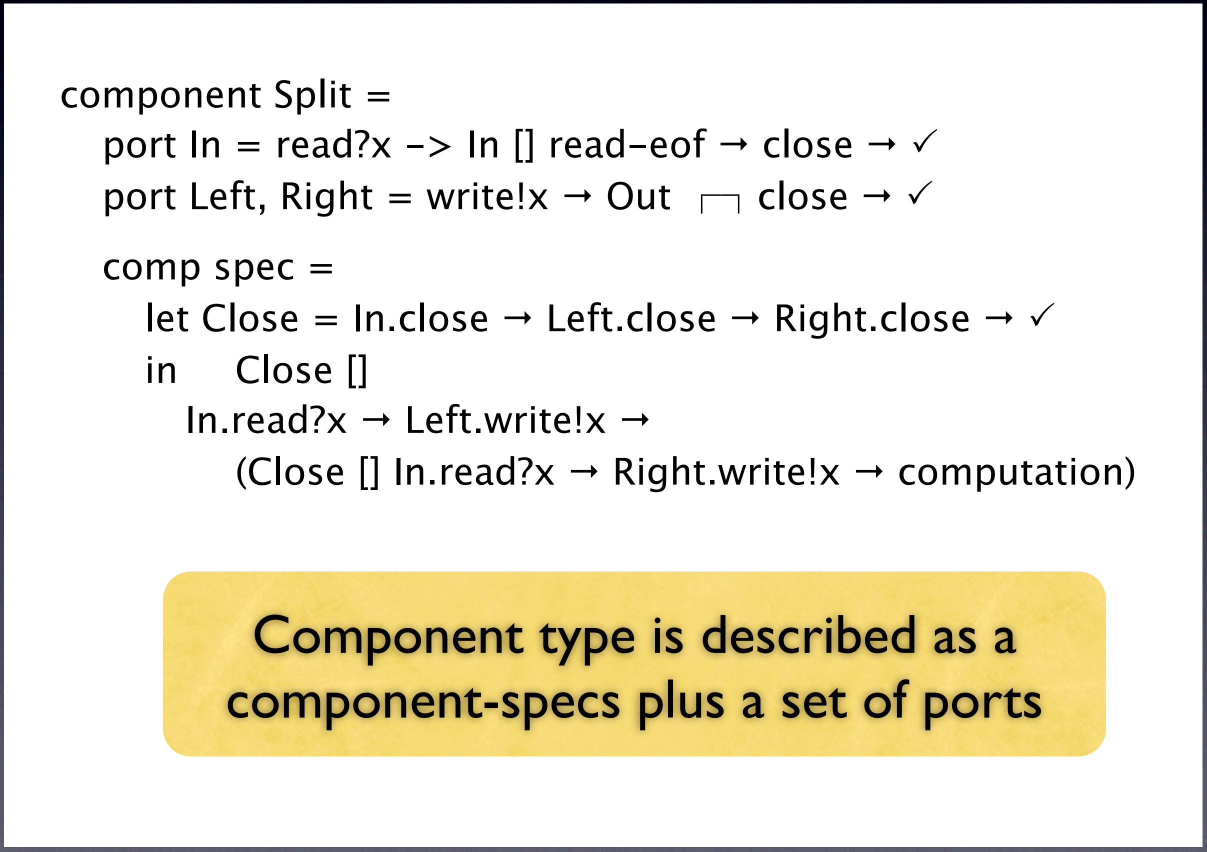
Shaw, DeLine, Klein, Ross, Young and Zelesnik, "Abstractions for software architectures and tools to support them", Trans. on Soft. Eng. 21(4):314-335.

Wright

- Focus on making interaction formal
  - components interact through ports
  - connectors interact through roles
  - attachments are made by binding ports to roles
  - ports and roles are formally defined as CSP (communicating sequential processes).
  - i.e., a ***process*** description language for defining connector types as a protocol of interaction of components
  - what is a process? a "thing" that engages in communication/ interaction events in a sequence. an event can have associated data.

Allen & Garlan, "Formalizing architectural connection", ICSE 1994

Wright Component Description Example



```
component Split =
   port In = read?x -> In [] read–eof → close → ✓
   port Left, Right = write!x → Out  ⊓  close → ✓

   comp spec =
      let Close = In.close → Left.close → Right.close → ✓
      in     Close []
         In.read?x → Left.write!x →
            (Close [] In.read?x → Right.write!x → computation)
```

Component type is described as a component-specs plus a set of ports

Wright Connector Description Example

```
connector Pipe =
 role Writer = write!x → Writer ⊓ close → ✓
 role Reader = let ExitOnly = close → ✓
     in let DoRead = (read?x → Reader [] read–eof → ExitOnly)
     in DoRead ExitOnly
 glue = let ReadOnly = Reader.read!y → ReadOnly
                [] Reader.read–eof → Reader.close → ✓ []
Reader.close → ✓
     in let WriteOnly = Writer.write?x → WriteOnly [] Writer.close
→ ✓
     in Writer.write?x → glue [] Reader.read!y → glue
        [] Writer.close → ReadOnly [] Reader.close → WriteOnly
 spec ∀ Reader.read$_i$!y . ∃ Writer.write$_j$?x . i=j ∨ x=y
     ∧ Reader.read–eof ⇒ (Writer.close ∧ #Reader.read =
#Writer.write)
```

Roles: obligation of each participating component.

A glue spec: protocol description (coordination among roles)

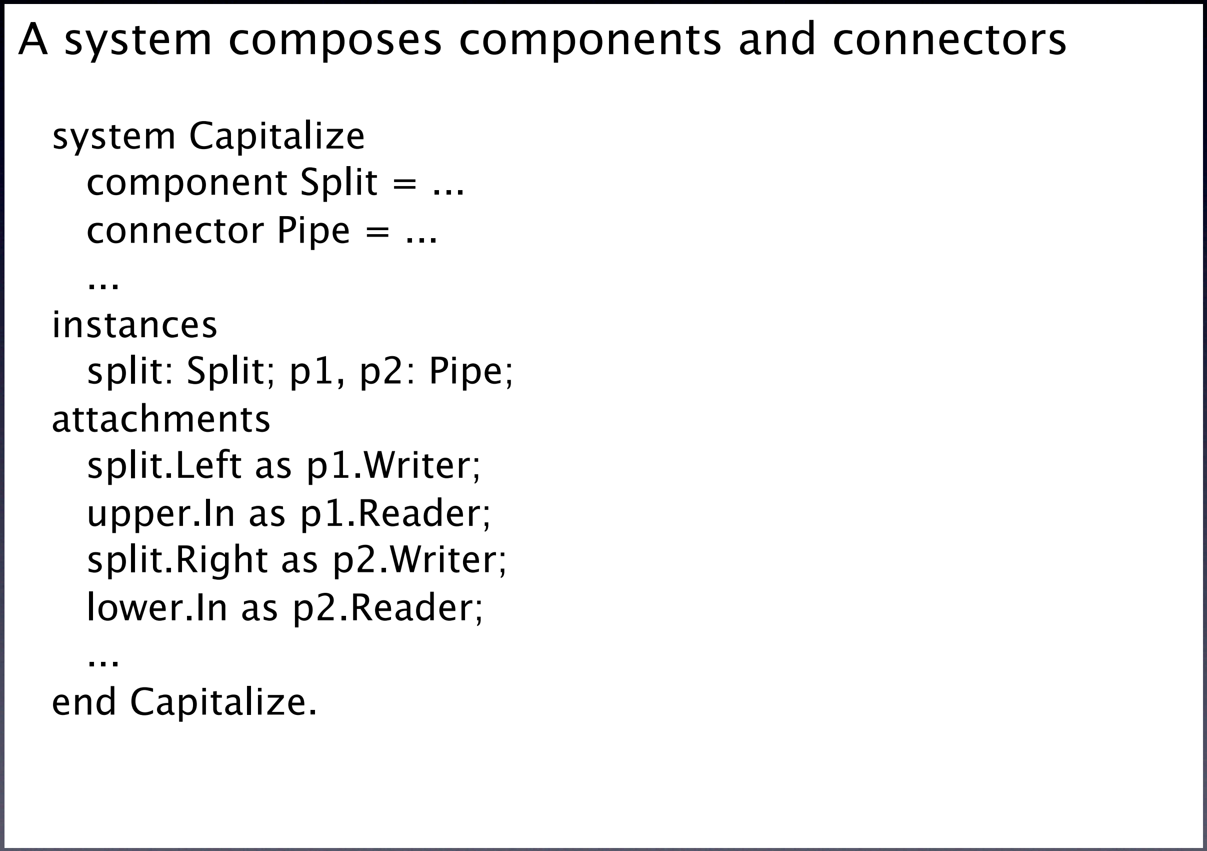
Connector type is described as a set of roles and a glue specification.

Wright Connector Description Example

```
connector Pipe =
 role Writer = write!x → Writer  ⊓  close → ✓
 role Reader = let ExitOnly = close → ✓
     in let DoRead = (read?x → Reader [] read–eof → ExitOnly)
     in DoRead ExitOnly
 glue = let ReadOnly = Reader.read!y → ReadOnly
                [] Reader.read–eof → Reader.close → ✓ []
Reader.close → ✓
     in let WriteOnly = Writer.write?x → WriteOnly [] Writer.close
→ ✓
     in Writer.write?x → glue [] Reader.read!y → glue
        [] Writer.close → ReadOnly [] Reader.close → WriteOnly
 spec ∀ Reader.read_i!y . ∃ Writer.write_j?x . i=j ∨ x=y
     ∧ Reader.read–eof ⇒ (Writer.close ∧ #Reader.read =
#Writer.write)
```

Roles specify possible behaviors (the steps that can make up a protocol and possible ordering). Glue describes how behaviors are combined across roles.

Wright System Description



A system composes components and connectors

```
system Capitalize
   component Split = ...
   connector Pipe = ...
   ...
instances
   split: Split; p1, p2: Pipe;
attachments
   split.Left as p1.Writer;
   upper.In as p1.Reader;
   split.Right as p2.Writer;
   lower.In as p2.Reader;
   ...
end Capitalize.
```

ADL to ArchJava

- Existing ADLs decouple implementation code from architecture, allowing inconsistencies, causing confusion, violating architectural properties, and inhibiting software evolution.

ArchJava

- ArchJava is an extension to Java that seamlessly unifies software architecture with implementation.
- It also ensures that the implementation conforms to architectural constraints
- It ensures traceability between architecture and code and support the co-evolution of architecture and implementation

ArchJava: Connecting Software Architecture to Implementation, Jonathan Aldrich, Craig Chambers and David Notkin [ICSE 2002]

ArchJava Component Example

```
public component class Parser {
  public port in {
    provides void setInfo(Token symbol,
                          SymTabEntry e);
    requires Token nextToken()
                   throws ScanException;
  }
  public port out {
    provides SymTabEntry getInfo(Token t);
    requires void compile(AST ast);
  }

  void parse(String file) {
    Token tok = in.nextToken();
    AST ast = parseFile(tok);
    out.compile(ast);
  }

  AST parseFile(Token lookahead) { ... }
  void setInfo(Token t, SymTabEntry e) {...}
  SymTabEntry getInfo(Token t) { ... }
  ...
}
```

ArchJava Component Example

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    requires void compile(AST ast);
  }

  void parse(String file) {
    Token tok = in.nextToken();
    AST ast = parseFile(tok);
    out.compile(ast);
  }

  AST parseFile(Token lookahead) { ... }
  void setInfo(Token t, SymTabEntry e) {...}
  SymTabEntry getInfo(Token t) { ... }
  ...
}
```

A ***component*** can only communicate with other components through explicitly declared ports; regular method calls between components are not allowed.

A ***port*** represents a logical communication channel between a component and other components that it is connected to.

ArchJava Component Example

```
public component class Parser {
  public port in {
    provides void setInfo(Token symbol,
                          SymTabEntry e);
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  }

  void parse(String file) {
    Token tok = in.nextToken();
    AST ast = parseFile(tok);
    out.compile(ast);
  }

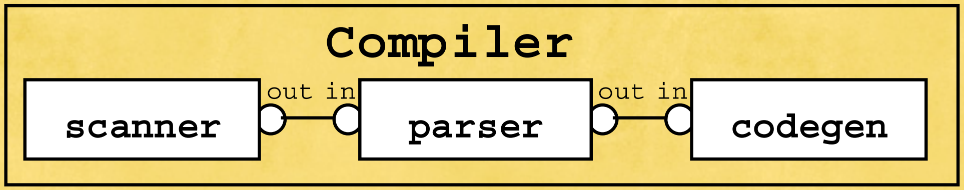
  AST parseFile(Token lookahead) { ... }
  void setInfo(Token t, SymTabEntry e) {...}
  SymTabEntry getInfo(Token t) { ... }
  ...
}
```

provides: a provided method is implemented by the component and is available to be called by other components connected to this port.

requires: each required method is provided by some other component connected to this port.

broadcasts: the same as required except that they can be connected to any number of implementations and must return void.

ArchJava Connector Example



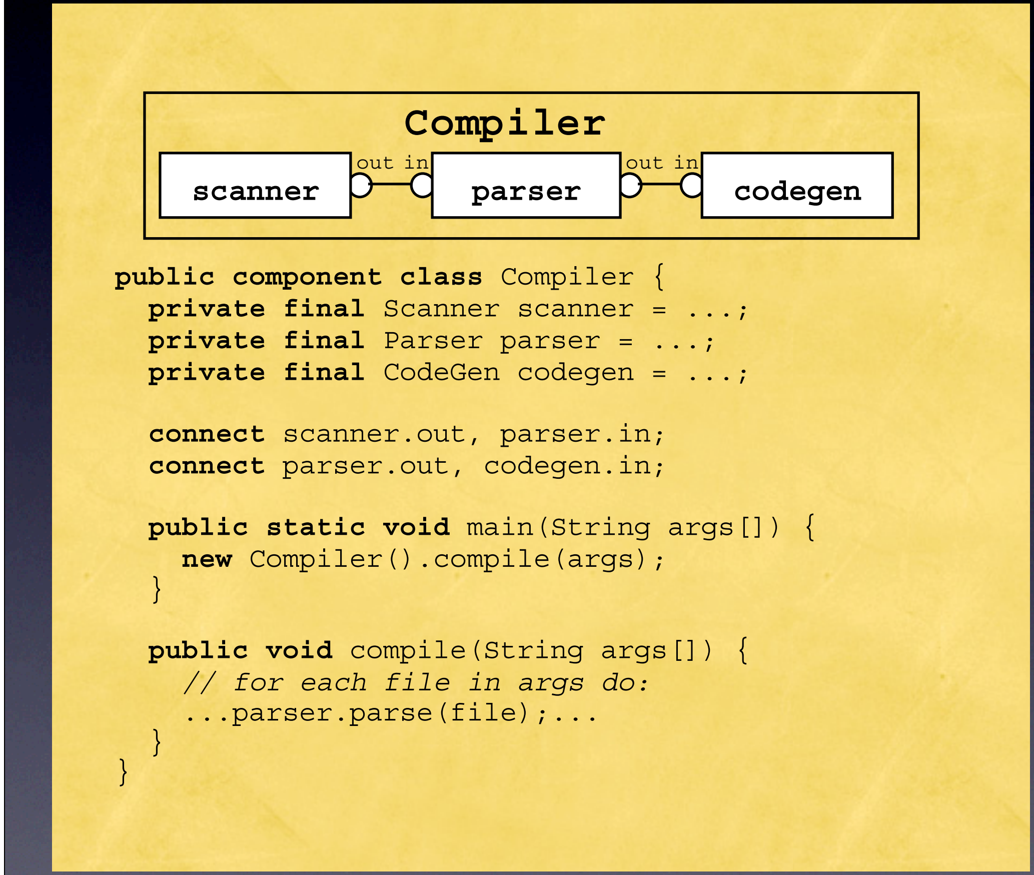
```
public component class Compiler {
  private final Scanner scanner = ...;
  private final Parser parser = ...;
  private final CodeGen codegen = ...;

  connect scanner.out, parser.in;
  connect parser.out, codegen.in;

  public static void main(String args[]) {
    new Compiler().compile(args);
  }

  public void compile(String args[]) {
    // for each file in args do:
    ...parser.parse(file);...
  }
}
```

ArchJava Connector Example



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  public static void main(String args[]) {
    new Compiler().compile(args);
  }

  public void compile(String args[]) {
    // for each file in args do:
    ...parser.parse(file);...
  }
}
```

connect: this primitive connects two or more ports together, binding each required method to a provided method with the same name and signature.

Connection consistency checks are performed to ensure that each required method is bound to a unique provided method.

ArchJava: Connector TypeChecking

- ArchJava is integrated with Java
- ArchJava makes dependencies explicit, reduces coupling, and promotes understanding of components in isolation
- ArchJava gives you a mechanism for expressing and checking connections but those connections are modeled as individual method calls

Take away message

- Software Architecture is a high-level abstraction of software design.
- A software architecture is usually specified by its components, connections, and composition mechanism.
- Active research in architecture description languages, architectural styles, and enforcing architecture at an implementation level.