CSEP504: Advanced topics in software systems

• Software architecture: design-based
  – Formal reasoning about properties
  – Static vs. dynamic architectures
• Software architecture: property-based
  – Autonomic systems
  – Relationship to model-based design
• Motivation for biologically-inspired architectures
  (Lecture 3, Brun)
Two categories: *very* soft distinction

- **Software architecture: design-oriented**
  - Based in software design, in defining taxonomies based on experience, etc.
- **Software architecture: property-oriented**
  - Based on a desire to design software systems with a particular property – such as autonomic systems, fault-tolerance, privacy, etc.
Design-based software architecture

- Two primary goals
  - Capturing, cataloguing and exploiting experience in software designs
  - Allowing reasoning about classes of designs
- Composition of components and connectors
  - Components are the core computational entities
  - Connectors are the core ways in which components communicate and interact
  - Under constraints – only some combinations are permitted to allow demonstration of the presence or absence of key properties
Describing architectures

- There are, roughly, two approaches to describing software architectures
- The first – and the most heavily explored – is to define an ADL – architecture description language
- The second is to extend a programming language with architectural constructs
Partial Comparison

**ADL**
- √ Can focus on architectural issues
- √ Can allow architecture-related analysis
- √ Separates architectural activities from lower-level activities
- X Separates architecture from software, allowing drift
- X Requires additional learning and experience by developers, testers, etc.

**Extend PL**
- √ Provides transition to adopt architecture for existing systems
- √ Connects architecture with program, reducing drift
- √ Incremental cost to train developers, testers, etc.
- X Fuzzier distinction between architecture and program
- X May constrain possible analyses
First generation ADLs

- ACME (CMU/USC)
- Rapide (Stanford)
- Wright (CMU)
- Unicon (CMU)
- Aesop (CMU)
- MetaH (Honeywell)
- C2 SADL (UCI)
- SADL (SRI)
- Lileanna
- UML
- Modechart

- From 1999 MCC report
- Much of the following material is adapted from that report
Second generation ADLs

• Changes from MCC list with respect to Wikipedia’s list (1/9/2010)
• Added
  – LePUS3 and Class-Z (University of Essex)
  – ABACUS (UTS)
  – AADL (SAE) - Architecture Analysis & Design Language
• Removed:
  – UML
  – Modechart
ADL +/-’s

Positives

• Formal representation of architecture
• Higher level system description than previously possible
• Permit analysis of architectures – completeness, consistency, ambiguity, and performance
• Can support automatic generation of software systems

Negatives

• No universal agreement on what ADLs should represent, particularly as regards the behavior of the architecture
• Tend to be very vertically optimized toward a particular kind of analysis
Architecture definition

- Components
- Connectors
- Configurations (topologies)
- Constraints (restrictions)
MCC 1999 Report: ACME

• Developed jointly by Monroe, Garlan (CMU), Wile (USC)
• A general purpose ADL originally designed to be a lowest common denominator interchange language
• Simple, consistent with interchange objective, allowing only syntactic linguistic analysis
Simple ACME Example (Client-Server)

System simple_cs = {
    Component client = {Port send-req}
    Component server = {Port receive-req}
    Connector rpc = {Roles {caller, callee}}
    Attachments :
        {client.send-req to rpc.caller;
         server.receive-req to rpc.callee}
}
1999 MCC: Rapide

- By Luckham at Stanford
- A general purpose ADL designed with an emphasis on simulation yielding partially ordered sets of events
- Fairly sophisticated, including data types and operations
- Analysis tools focus on posets
  - matching simulation results against patterns of allowed/prohibited behaviors
  - some support for timing analysis
  - focus on causality
Rapide

• Components
  – Interface objects
  – Architecture that implements an interface
  – Module that implements an interface
• Connections
  – Connects “sending interfaces” to “receiving interfaces”
  – Components communicate through connections by calling actions or functions in its own interface
  – Events generated by components trigger event pattern connections between their interfaces – basic, pipe, agent
Rapide constraints

• Pattern
  – Bound execution in terms of event patterns
  – Appear in an interface and/or architecture definition
  – `[label] filter_part constraint_body`
  – Filter creates context
  – Constraint body constrains computation in context

• Sequential
  – Bound execution in terms of boolean expressions
  – Normally appear in module level behavior
  – Applied to parameters, types, objects and statements
Rapide example

type Producer (Max : Positive) is interface
  action out Send (N: Integer);
  action in Reply(N : Integer);
behavior
  Start => send(0);
  (?X in Integer) Reply(?X) where ?X<Max => Send(?X+1);
end Producer;

type Consumer is interface
  action in Receive(N: Integer);
  action out Ack(N : Integer);
behavior
  (?X in Integer) Receive(?X) => Ack(?X);
end Consumer

architecture ProdCon() return SomeType is
  Prod : Producer(100); Cons : Consumer;
connect
  (?n in Integer) Prod.Send(?n) => Cons.Receive(?n);
  Cons.Ack(?n) => Prod.Reply(?n);
end architecture ProdCon;
Wright: Garlan and Allen (CMU)

- ADL designed with an emphasis on analysis of communication protocols
- Wright uses a variation of CSP to specify the behaviors of components, connectors, and systems
  - CSP: Hoare’s Communicating Sequential Processes
- Syntactically similar to ACME
- Wright analysis focuses on analyzing the CSP behavior specifications
System `simple_cs`

Component `client`

  port `send-request` = [behavioral spec]
  spec = [behavioral spec]

Component `server`

  port `receive-request` = [behavioral spec]
  spec = [behavioral spec]

Connector `rpc`

  role `caller` = (request!x -> result?x -> caller) ^ STOP
  role `callee` = (invoke?x -> return!x -> callee) [] STOP
  glue = (caller.request?x -> callee.invoke!x
         -> callee.return?x -> callee.result!x -> glue) [] STOP

Instances

  s : server; c : client; r : rpc

Attachments :

  client.send-request as rpc.caller
  server.receive-request as rpc.callee

end `simple_cs`. 

MCC “other” ADLs

- **Unicon (Shaw et al. @ CMU)**
  - An emphasis on generation of connectors
  - Treatment of connectors as first class objects, which also supports generation n Unicon as a language focuses primarily on the basic
- **MetaH (Honeywell)**
  - Domain specific ADL aimed at guidance, navigation, and control applications with ControlH
  - Sophisticated tool support available
- **C2 SADL (Taylor/Medvidovic @ UCI)**
  - Emphasis on dynamism
- **SADL (Moriconi/Riemenschneider @ SRI)**
  - Emphasis on refinement mappings
MCC: UML as an ADL

• Major positives: lowers entry barrier, enables use of mainstream modeling approaches and tools
• Major negatives
  – Encourages an object connection architecture rather than interface connection architecture
  – Weakly integrated models with inadequate semantics for automated analysis
  – Connectors are not first class objects
  – Visual notation with ambiguity
CSP (Wikipedia 1/11/10) [for Wright]

• Communicating Sequential Processes (CSP) is a formal language for describing patterns of interaction in concurrent systems. It is a member of the family of mathematical theories of concurrency known as process algebras, or process calculi. …

• CSP was first described in a 1978 paper by C. A. R. Hoare… CSP has been practically applied in industry as a tool for specifying and verifying the concurrent aspects of a variety of different systems, such as the T9000 Transputer, as well as a secure ecommerce system. …
CSP vending machine example

• Three event types
  – Inserting a **coin** into the machine
  – Inserting a pre-paid **card** into the machine
  – Extracting a **chocolate** from the machine

• Examples
  – \((\text{coin} \rightarrow \text{STOP})\)
  – **Person** = \((\text{coin} \rightarrow \text{STOP}) \sqcap (\text{card} \rightarrow \text{STOP})\)
  – **SVM** = \((\text{coin} \rightarrow (\text{choc} \rightarrow \text{SVM}))\)
  – …
A process is an entity that engages in communication events.

Events may be primitive or they can have associated data: $e?x$ and $e!x$ represent input and output of data, respectively.

The simplest process **STOP** engages in no events.

The “success” event is $\checkmark$.

A process that engages in event $e$ and then becomes $P$ is denoted $e \rightarrow P$. 
A process that can behave like $P$ or $Q$, where the choice is made by the environment, is $P \parallel Q$

A process that can behave like $P$ or $Q$, where the choice is made non-deterministically by the process itself, is $P \cap Q$

$P_1 \parallel P_2$ is a process whose behavior is permitted by both $P_1$ and $P_2$ and for events that both processes accept

A successfully terminating process is $\S$, which is the same as $\sqrt{\rightarrow} \text{STOP}$
Wright example

• A shared memory connector, with different forms of initialization
• Any of the roles can either get or set the value repeatedly, terminating at any time. The overall communication is complete only when all participants are done with the data
• This version includes no initialization

Style SharedData

Connector SharedData1
Role User1 = set → User1 ⊑ get → User1 ⊑ §
Role User2 = set → User2 ⊑ get → User2 ⊑ §

Glue = User1.set → Glue ⊑ User2.set → Glue
    ⊑ User1.get → Glue ⊑ User2.get → Glue ⊑ §

End Style
With initialization

- This definition indicates that there is a distinguished role, **Initializer**, that must supply the initial value.
- The **Initializer** agrees to set the value before getting it.
- The glue ensures that this will occur before the other participant (User) gets or sets a variable.

```plaintext
component Shared Data2 =
  role Initializer =
    let A = set → A ⊲ get → A ⊲ §
    in set → A
  role User = set → User ⊲ get → User ⊲ §
  glue = let Continue = Initializer.set → Continue ⊲ User.set → Continue
  ⊲ Initializer.get → Continue
  ⊲ User.get → Continue ⊲ §
  in Initializer.set → Continue ⊲ §
```
With lazy initialization

• Does not require that the other participant wait for initialization to proceed

connector Shared Data3 =
  role Initializer =
    let A = set -> A □ get -> A □ $
    in set -> A
  role User = set -> User □ get -> User □ $
  glue = let Continue = Initializer.set -> Continue
        □ User.set -> Continue
        □ Initializer.get -> Continue
        □ User.get -> Continue □ $
        in Initializer.set -> Continue
        □ User.set -> Continue □ $
Looks good but...

connector Bogus =

role User1 = set → User1 □ get → User1 □ §
role User2 = set → User2 □ get → User2 □ §
glue = let Continue = User1.set → Continue
    □ User2.set → Continue
    □ User1.get → Continue
    □ User2.get → Continue □ §
    in User1.set → Continue □ User2.set → Continue □ §
Analysis

- An analysis of a well-formed system should be able to show that it is deadlock-free
- For architectural connectors, the means avoiding the situation in which two components can wait in the middle of an interaction, each port expecting the other to take some action that will never happen
- A connector process is free from deadlock if whenever it cannot make progress, then the last event to have taken place must have been ✓
- In other words, the roles and glue work in such a way that if the overall connector process stops, it will be in a situation that is a success state for all the parties.
Wright tools

- Allow you to assert deadlock-freedom and to have it automatically checked
  - It converts Wright descriptions into FDR, a commercial model-checker that offers the choice of verification using CSP Traces Refinement, Failures Refinement, and Failures-Divergences Refinement models
- Asserts might be, for the shared data example:
  - ? DFA [FD=User1
  - ? DFA [FD=User2
  - ? DFA [FD=SharedData1
- DFA means DeadlockFree Process
- FD means Failures-Divergences Refinement model
- Returns true if proven, false with counterexample otherwise
Counterexample example

- √ DFA [FD=User1
- √ DFA [FD=User2
- X DFA [FD=Bogus

- The connector glue requires that User1 or User2 initialize the variable, but does not specify which one
- If either begins with a set, then that event will occur first and all is OK
- But if User1 and User2 both attempt to perform an initial get – which is entirely legal – then the connector will deadlock
- The tool identifies a counterexample
  - The Glue process is ready to accept
    \{√,User1.set,User2.set\} while both the User1 and User2 processes will only accept get
connector Pipe =
  role Writer = write$\rightarrow$Writer $\sqcap$ close$\rightarrow$ $\checkmark$
  role Reader = let ExitOnly = close$\rightarrow$ $\checkmark$
    in let DoRead = (read$\rightarrow$Reader $\sqsubseteq$ read-eof$\rightarrow$ExitOnly)
    in DoRead $\sqcap$ ExitOnly
  glue = let ReadOnly = Reader.read$\rightarrow$ReadOnly
             $\sqsubseteq$ Reader.read-eof$\rightarrow$Reader.close $\rightarrow$ $\checkmark$
             $\sqsubseteq$ Reader.close $\rightarrow$ $\checkmark$
    in let WriteOnly = Writer.write$\rightarrow$WriteOnly $\sqsubseteq$ Writer.close $\rightarrow$ $\checkmark$
    in Writer.write$\rightarrow$glue $\sqsubseteq$ Reader.read$\rightarrow$glue
             $\sqsubseteq$ Writer.close$\rightarrow$ReadOnly $\sqsubseteq$ Reader.close$\rightarrow$WriteOnly

Fig. 5. A pipe connector.
For every trace in which `Reader.read-eof` occurs, there must also be an occurrence of the event `Writer.close`, and the number of times that `Reader.read` has occurred equals the number of occurrences of `Writer.write`. That is, before `eof` is signaled, all data have been read, and the pipe is closed.
ArchJava: PL++ rather than ADL

• **ArchJava**: Jonathan Aldrich, UW⇒CMU (much more since the material here)
• Combine architectural description with programming language
  – Ensure implementation code obeys architectural constraints.
  – Doesn’t preclude common programming idioms
  – Allow easier traceability between architecture and implementation
• ArchJava uses a type system to guarantee communication integrity between an architecture and its implementation
Communication integrity

• Each component in the implementation may only communicate directly with the components to which it is connected in the architecture [Luckham & Vera]
• If “out of band” communication can take place, most properties are hard to guarantee
• Related to some degree to The Law of Demeter [Lieberherr et al.]
  – A can call B, but A cannot use B to allow A to call C – this would allow A to have knowledge of B’s internal structure
  – B can be modified (if needed) to handle this for A, or A can obtain a direct reference to C
  – Wikipedia [1/10/2010]: “In particular, an object should avoid invoking methods of a member object returned by another method. For many modern object oriented languages that use a dot as field identifier, the law can be stated simply as ‘use only one dot’. That is, the code ‘\texttt{a.b.Method()}’ breaks the law where ‘\texttt{a.Method()}’ does not.”
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);
    }
    public void parse() {
        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 at its level in
  the architecture through explicitly declared ports—regular method calls
  between components are not allowed
• A port represents a logical communication channel between a component and
  one or more components that it is connected to
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();...
    }
}
Communication integrity

- Ensures that the implementation does not communicate in ways that could violate reasoning about control flow in the architecture
- A component instance A may not call the methods of another component instance B unless
  - B is A’s subcomponent, or
  - A and B are sibling subcomponents of a common component instance that declares a connection or connection pattern between them
How does ArchJava work?

| CL | ::= class C extends C { C f; K M } |
| CP | ::= component class P extends E { C f; K M port z { R M } X } |
| K  | ::= E(C f) (super(f); this.f = f;) |
| M  | ::= T m(T x) { return e; } |
| R  | ::= requires T m(T x) _ |
| X  | ::= connect pattern (P,z) |

\[
\begin{align*}
\text{e} & ::= v \\
& \quad \text{new } E(e) \\
& \quad e.f \\
& \quad e.m(e) \\
& \quad (T)e \\
& \quad \theta > e \\
\text{v} & ::= x \\
& \quad \text{connect}(\overline{v}.z) \\
& \quad \text{error} \\
\text{T,V} & ::= E \\
& \quad \text{v}.z \\
& \quad U(v.z) \\
\text{S} & ::= \ell \rightarrow E_\ell(\ell) \\
\Gamma & ::= x \rightarrow T \\
\Sigma & ::= \ell \rightarrow T \\
\ell,\theta,\zeta & \in \text{Locations}
\end{align*}
\]

Figure 5. ArchFJ Evaluation Rules
More...

Figure 6. ArchFJ Subtyping

\[
T \ll T
\]
\[
T \ll T' \quad T' \ll T' \quad T' \ll T
\]
\[
CT(E) = \{\text{component}\} \text{ class } E \text{ extends } F \{ \ldots \}
\]
\[
E \ll F
\]
\[
T \ll \text{Object}
\]
\[
\frac{v.z \in v.z}{\cup (v.z) \ll v.z}
\]

Figure 7. ArchFJ Typechecking

\[
\begin{align*}
\Gamma, \Sigma, E & \vdash \ell : \Sigma(\ell) \\
\Gamma, \Sigma, E & \vdash x : \Gamma(x) \\
\Gamma, \Sigma, F & \vdash e : C \\
\Gamma, \Sigma, E & \vdash \text{fields}(E) = D \\
\Gamma, \Sigma, E & \vdash \text{new } E(e) : E \\
\Gamma, \Sigma, E & \vdash \overline{v} : P
\end{align*}
\]
\[
\begin{align*}
\Gamma, \Sigma, E & \vdash e_0 : E_0 \\
\Gamma, \Sigma, E & \vdash e_0 : f_i : C_i
\end{align*}
\]
\[
\begin{align*}
\Gamma, \Sigma, E & \vdash e : T_0 \\
\Gamma, \Sigma, E & \vdash e_0 : T_0 \\
\Gamma, \Sigma, E & \vdash \text{mtype}(m, T_0) = T \rightarrow T
\end{align*}
\]
\[
\begin{align*}
\Gamma, \Sigma, E & \vdash \ell : F \\
\Gamma, \Sigma, F & \vdash e : T
\end{align*}
\]
Data sharing

- ArchJava extensions to describe architectural constraints on data sharing (using alias control analysis)
- Can describe data that is confined within a component, passed linearly from one component to another, or shared temporarily or persistently between components.
- Careful use of sophisticated language/type constructs like uniqueness, lending, mutability, etc.
Quick recap

- Architectural description via specially designed languages (ADLs) and via programming language extensions
- Reasoning about architectural properties
  - ADLs (like Wright) allow the definition of properties to check within the scope of the language and analysis tools
  - PL++ (like ArchJava) define the properties to always be checked
- Other tradeoffs with respect to adoption, to implementation issues, etc.
Static vs. dynamic architectures

- ACME, WRIGHT, etc. define static architectures – essentially, all processes need to be known statically (and thus not created during execution of the implementation)
- The need for dynamic architectures – creation and management of processes at run-time – has been a hot topic for at least a decade (in the software architecture research area, that is)
- Lots of work on this, but I’ll focus on
ICSE N-10 award paper

• This paper received the ICSE 2008 Most Influential Paper Award, which recognizes the paper with the most influence on theory or practice during the 10 years since its publication

• The following (partial set of) slides are stolen from the retrospective talk at ICSE 2008 by Peyman, Neno and Dick (http://www.ics.uci.edu/~peymano/dynamic-arch/)
Change *during* runtime?

- Critical systems require “continuous availability”
- Power grid, financial systems, ...
- Increasingly important in everyday systems
New software is available for your computer.

Installing this software may take some time. If you’re not ready to install now, you can choose Software Update from the Apple menu later.

The 10.5.1 Update is recommended for all users running Mac OS X Leopard and includes general operating system fixes that enhance the stability, compatibility, and security of your Mac.

For detailed information on this update, please visit this website:
For detailed information on security updates, please visit this website:

Note: Use of this software is subject to the original Software License Agreement(s) that accompanied the software being updated. A list of Apple SLAs may be found here:

Restart will be required.
State of the Practice

- redundant and fault-tolerant hardware
- “hot pluggable” drives and memory
- system virtualization (ala VMware and Xen)
- binary code patching
- programming language facilities for dynamic loading, linking, and patching of code
- software designed for fault tolerance (architectural styles and patterns)
Towards a Unifying Framework

All approaches:

1. Use a “model” to highlight some system details while hiding others

2. Grapple with 5 aspects of runtime change:
   a. evolve behavior
   b. evolve state
   c. adjust execution context
   d. asynchronous change
   e. probe running system
Dynamic Adaptation Models I

- Prior to our ICSE 1998 paper
- Style-based models: CHAM, graph-grammars
- ADL-based models: Darwin, Dynamic Wright, Rapide
- Did not gain wide adoption
- Lack of system-level facilities
- Constrained notion of dynamism
Dynamic Adaptation Models II

- Subsequent to our ICSE 1998 paper
- “Figure 8” model: system adaptation driven by architecture
Dynamic Adaptation Models III

- Rainbow: similar to “Figure 8”
- Self-managed systems: dynamic plan generation
Research Projects

- Aura: QoS-driven system reconfiguration
- MobiPads: QoS optimization via dynamic reconfiguration
- Siena: Client-, server-, and network-level dynamism
- Grid computing: Dynamic addition and removal of computing resources

Commercial Solutions

- Koala: predefined dynamic adaptations via options
- Skype
  - Promotion/demotion of nodes
  - P2P-based adaptations
- MapReduce: automatic data rerouting from failed to live nodes
Promising Directions

• A simple message: if you want or need adaptable applications you can either:
  • Make no constraints on developers
  • ... and then work like crazy to try to obtain adaptation
  • Constrain development to make adaptation easier and predictable
• This should not be news: the message is styles
How Do You Make Adaptation Easier?

- Make the elements subject to change identifiable
- Make interaction controllable
- Provide for management of state
Lots of Successful Examples

- Pipe-and-filter
- Dynamic pipe-and-filter: Weaves
- Event-based systems: Field & pub-sub
- Event-based components and connectors: C2
- REST

<table>
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<th>Arch Style</th>
<th>Update Behavior</th>
<th>Update State</th>
<th>Update exec context</th>
<th>Asynchrony of change</th>
<th>Impl. probes</th>
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Checklists: an aside

• Last night my wife and I attended the Town Hall talk by Dr. Atul Gawande on his new book, The Checklist Manifesto
• Excerpts from Malcolm Gladwell’s review [amazon.com]
• “[H]e is really interested in a problem that afflicts virtually every aspect of the modern world—and that is how professionals deal with the increasing complexity of their responsibilities.

[56]
More from Gladwell

• “[H]e walks us through a series of examples from medicine showing how the routine tasks of surgeons have now become so incredibly complicated that mistakes of one kind or another are virtually inevitable: it’s just too easy for an otherwise competent doctor to miss a step, or forget to ask a key question or, in the stress and pressure of the moment, to fail to plan properly for every eventuality.

• “Gawande then visits with pilots and the people who build skyscrapers and comes back with a solution. Experts need checklists—literally—written guides that walk them through the key steps in any complex procedure. [H]e shows how his research team has taken this idea, developed a safe surgery checklist, and applied it around the world, with staggering success.”
So, role of checklists in software engineering?
Software architecture: property-oriented

• Based on a desire to design software systems with a particular property – such as autonomic systems, fault-tolerance, privacy, etc.
• But weren’t properties checked by ADLs, etc.?
• Absolutely.
• The difference in property-oriented (remember, I made that term up) is that the properties are described and the systems are produced – at least to the first order
  – In contrast to producing an architecture and ensuring it has properties
  – Perhaps this is at least as much an issue of generation as property-orientation
Model-based design

- [Wikipedia 1/11/10]: “... is a mathematical and visual method of addressing problems associated with designing complex control systems. ... Model-based design is a methodology applied in designing embedded software.”
- “The automotive industry has embraced model-based approaches mainly for the following reasons: (i) These graphical functional models visualize both the underlying mathematics (i.e. the differential equations) and the software that later on implements the functions on a specific processor. ... (ii) The models can be simulated ... very early in the development process. ... (iii) The models can be used as a basis for automatic code generation. This not only saves the efforts for the manual coding of the algorithms but also prevents transcription errors from the models to the code.”
- Also related to domain specific modeling

UW CSE P504  Niggemann, O. and Stroop, J. Models for model's sake: why explicit system models are also an end to themselves. 30th international Conference on Software Engineering (May 2008).
Principle of Alternatives [via E. Jackson]

- A high-level specification defines a design space
- The design space is complex, so some refinements are dead-ends and require backtracking through the design space
- Model-based design (or model integrated computing), provides tool support to simultaneously explore multiple alternatives

http://research.microsoft.com/en-us/um/people/ejackson/publications/asm07_pres.pptx
How to describe the design space?

- UML, UML variants (e.g., Executable UML), etc.
- MatLab/Simulink
- Design-time approximations of embedded system models
- Abstract state machines (E. Jackson et al.)
- Security policies as complex data + invariants
- Model transformations for semantic anchoring and code generation.
- Many more!

A Simple Example

We define a domain via term algebra equipped with a set of invariants written in a non-monotonic extension of Horn logic.

Constraint: Every graph must have a 3-cycle or 4-cycle

Break-down of encoding

Representation of domain in FORMULA syntax
Unrolling the Solution Space

The space of feasible solutions is created by unrolling paths from the root of the BCG to the leaves and introducing unique variables.
E. Jackson con’t

Walking the Solution Space

Each walk of the tree induces a constraint system represented as forest of union find trees.
E. Jackson con’t

Instantiating the model

If the constraint system is consistent, then a new model can be constructed by instantiating the “sink” variables

\[
\begin{align*}
V_1 &= a \\
V_2 &= b \\
V_3 &= c \\
V_4 &= d
\end{align*}
\]

\[
\{ \text{e}(a,c), \text{e}(c,d), \text{e}(d,a) \}
\]

The solution is the set of terms with function symbols completely in the domain signature.
Autonomic computing

• IBM’s term for self-managing and self-adaptive software systems
• Systems get more complex, increasing the difficulty and cost of building larger systems in new domains, etc.
• Autonomic computing systems are intended to adapt to unpredictable changes in the environment to remove the need for explicit adaption from the users and developers
Related to architecture how?

- Dependent on some of the kinds of mechanisms used in model based design
- Dependent on dynamic architectures
- Disciplined creation and adaptation of architectures that exhibit the self-manageability characteristic
IBM’s vision

• Kephart and Chess focused on the increasing “nightmare of pervasive computing” in which the complexity of the interactions leads us to a situation where the designers are deeply hampered.

• The essence of autonomic computing is to have the systems manage themselves, to deliver better system behavior while offloading tedious and error-prone system administrative activities from people.
IBM: four dimensions

- Self-Configuration: Automatic configuration of components
- Self-Healing: Automatic discovery and correction of faults
- Self-Optimization: Automatic monitoring and control of resources to ensure the optimal functioning with respect to the defined requirements
- Self-Protection: Proactive identification and protection from arbitrary attacks
IBM Autonomic Systems: 8 defining characteristics

- An autonomic computing system needs to "know itself" - its components must also possess a system identity. Since a "system" can exist at many levels, an autonomic system will need detailed knowledge of its components, current status, ultimate capacity, and all connections to other systems to govern itself. …

- An autonomic computing system must configure and reconfigure itself under varying (and in the future, even unpredictable) conditions. System configuration or "setup" must occur automatically, as well as dynamic adjustments to that configuration to best handle changing environments.

- An autonomic computing system never settles for the status quo - it always looks for ways to optimize its workings. It will monitor its constituent parts and fine-tune workflow to achieve predetermined system goals.
• An autonomic computing system must perform something akin to healing - it must be able to recover from routine and extraordinary events that might cause some of its parts to malfunction. It must be able to discover problems or potential problems, then find an alternate way of using resources or reconfiguring the system to keep functioning smoothly.

• A virtual world is no less dangerous than the physical one, so an autonomic computing system must be an expert in self-protection. It must detect, identify and protect itself against various types of attacks to maintain overall system security and integrity.

• An autonomic computing system must know its environment and the context surrounding its activity, and act accordingly. It will find and generate rules for how best to interact with neighboring systems. It will tap available resources, even negotiate the use by other systems of its underutilized elements, changing both itself and its environment in the process -- in a word, adapting.
• An autonomic computing system cannot exist in a hermetic environment. While independent in its ability to manage itself, it must function in a heterogeneous world and implement open standards -- in other words, an autonomic computing system cannot, by definition, be a proprietary solution.

• An autonomic computing system will anticipate the optimized resources needed while keeping its complexity hidden. It must marshal I/T resources to shrink the gap between the business or personal goals of the user, and the I/T implementation necessary to achieve those goals -- without involving the user in that implementation.
Great thoughts, but…

- How to achieve these characteristics?
- One key mechanism is closed control loops – from control theory
- That is, the system needs to be able to monitor itself and to adapt itself – without diverging into unexpected and unacceptable behaviors
- This requires explicit representations of many aspects of the system, so they can be accessed and modified at run-time

- At some level connected to mechanisms such as run-time code-generation, reflection, the meta-object protocol, open implementations, etc.
Key mechanism

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Cheng et al. 2009: Roadmap

Fig. 1. Activities of the control loop
Alternative mechanisms

• Biologically-inspired… stay tuned
Suggestions for third topic…

• …after architecture and tools?
Questions?