Rapid Development of Custom Software Architecture Design Environments

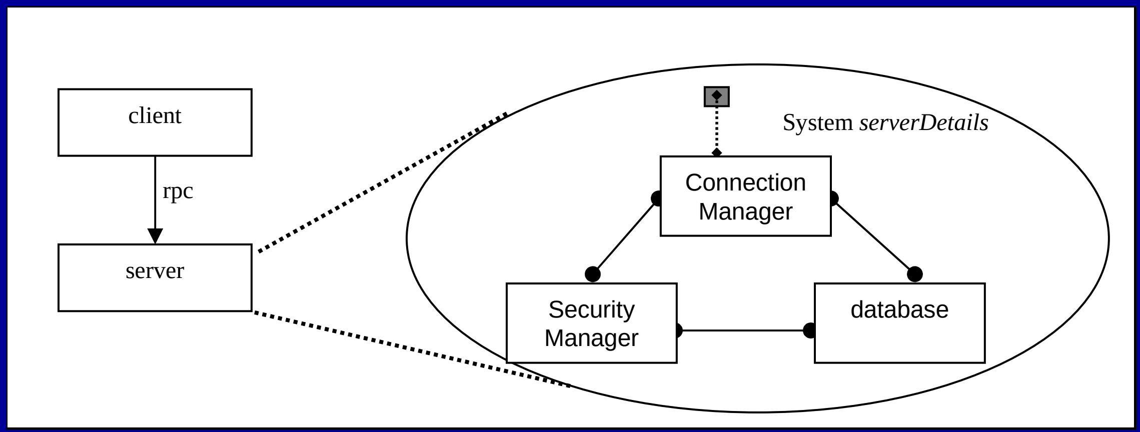
Robert T. Monroe
Carnegie Mellon University

Introduction and Motivation

- Introduction and motivation
- Capturing design expertise
- Customizing design environments
- Validation
- Wrapup

Software Architecture

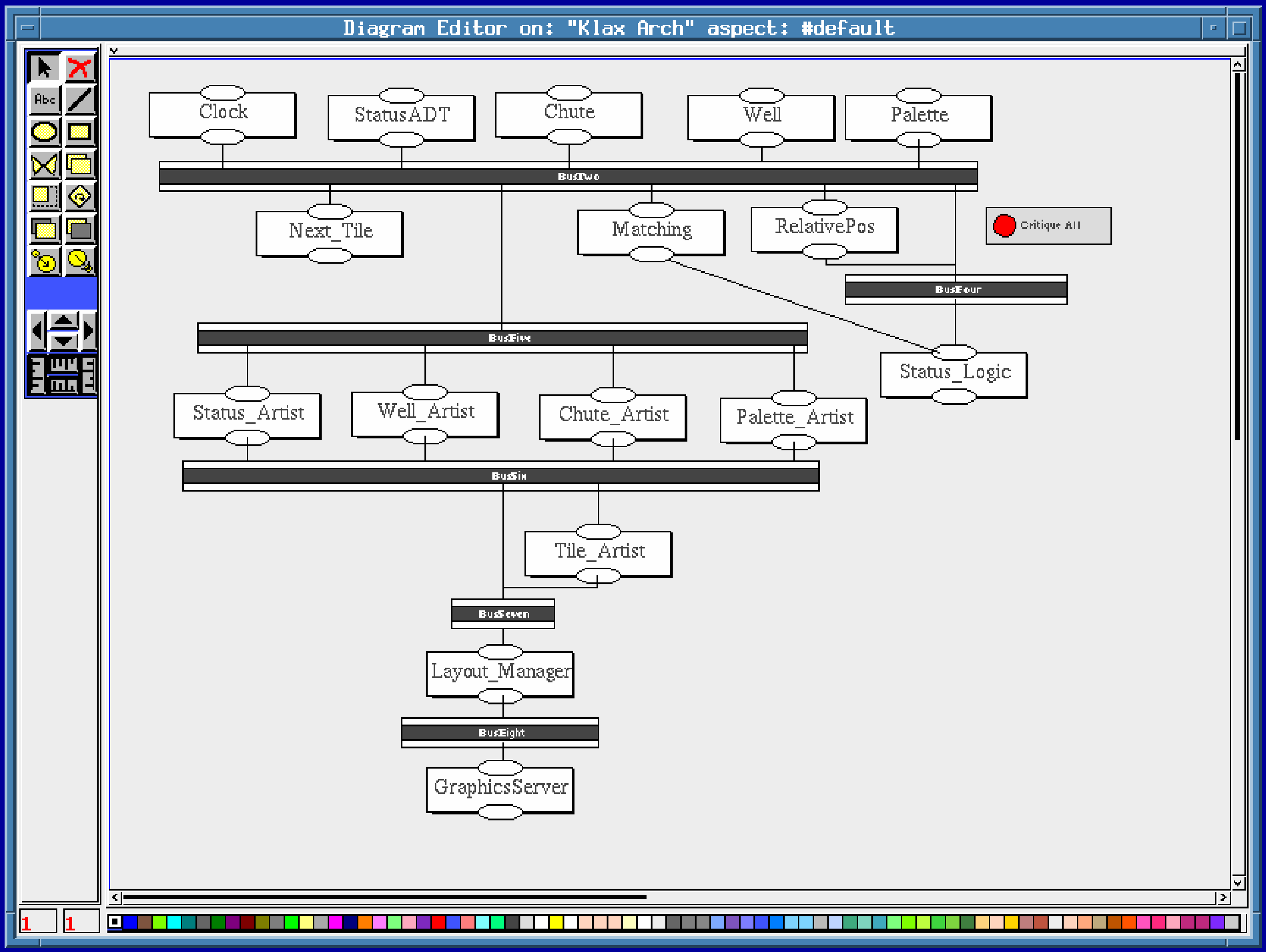
- Software architecture design focuses on:
  - Decomposing a system into components
  - Interactions between those components
  - Emergent global system properties



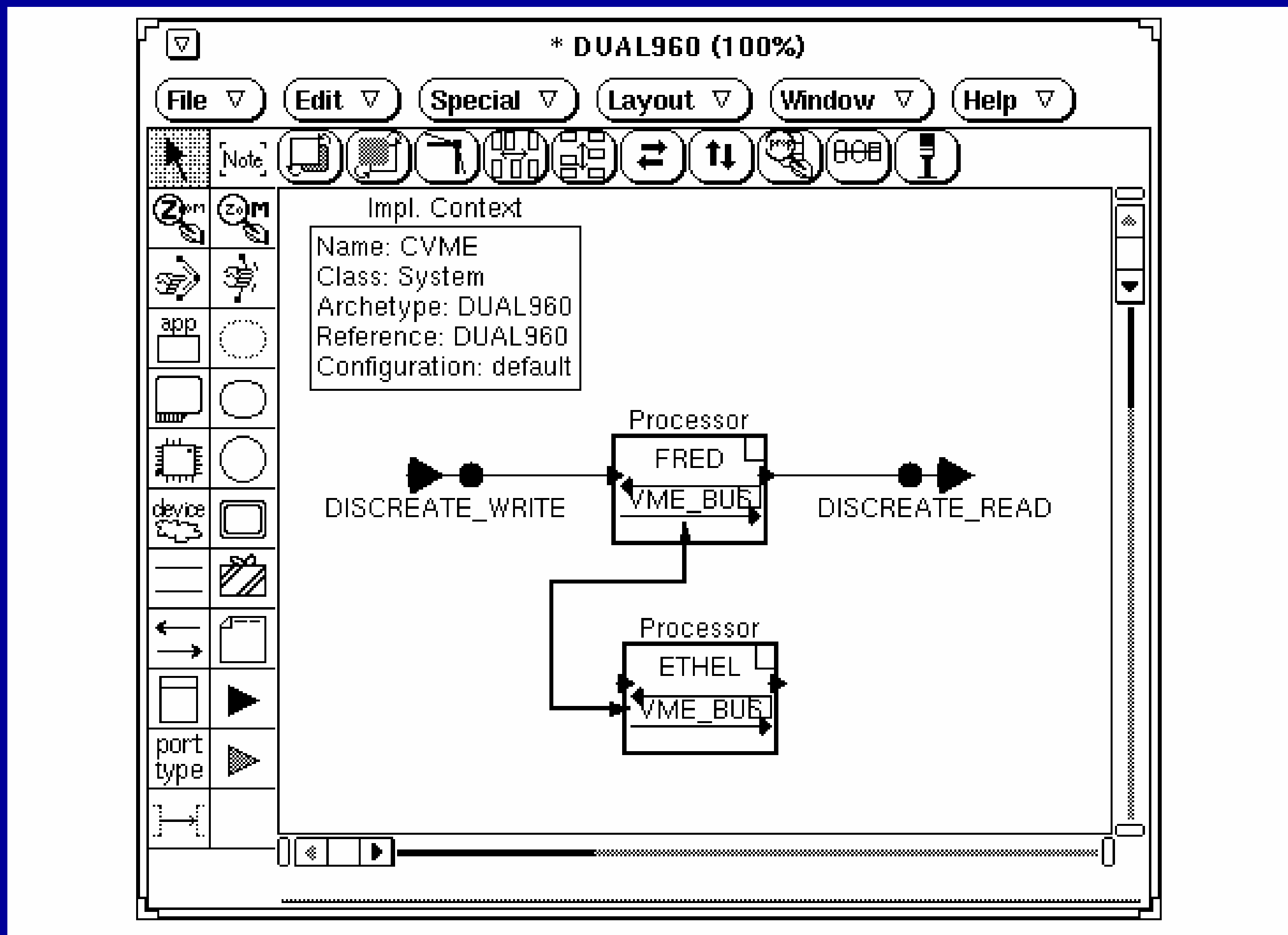
Premises

- Software Architects can benefit from powerful design environments
  - CAD in other engineering disciplines
  - Design analysis, guidance, and reuse
- The more closely a tool matches the problem it addresses, the more leverage that tool provides
  - Hammer ↔ Nail,   Screwdriver ↔ Screw

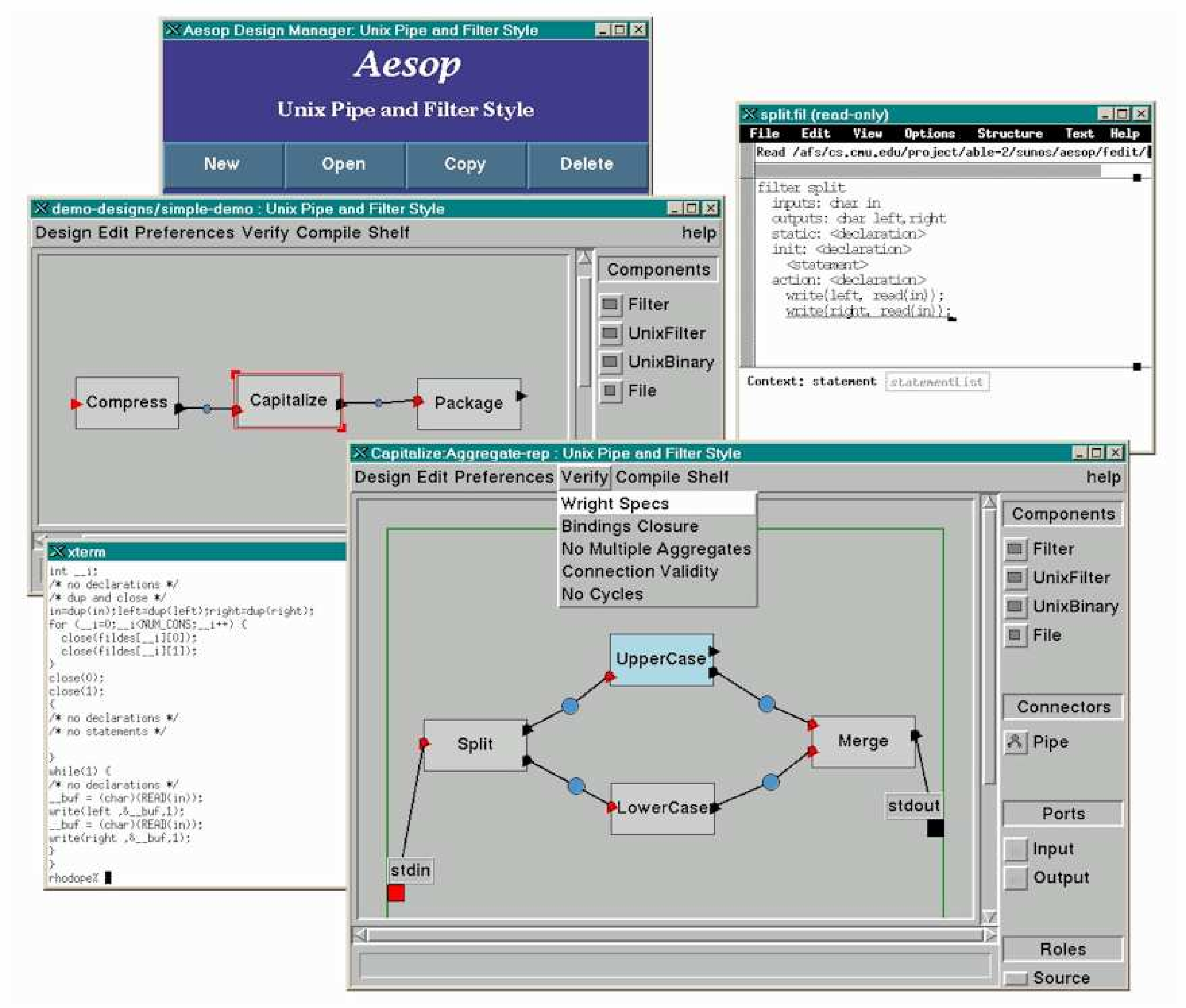
Example Environment: C2



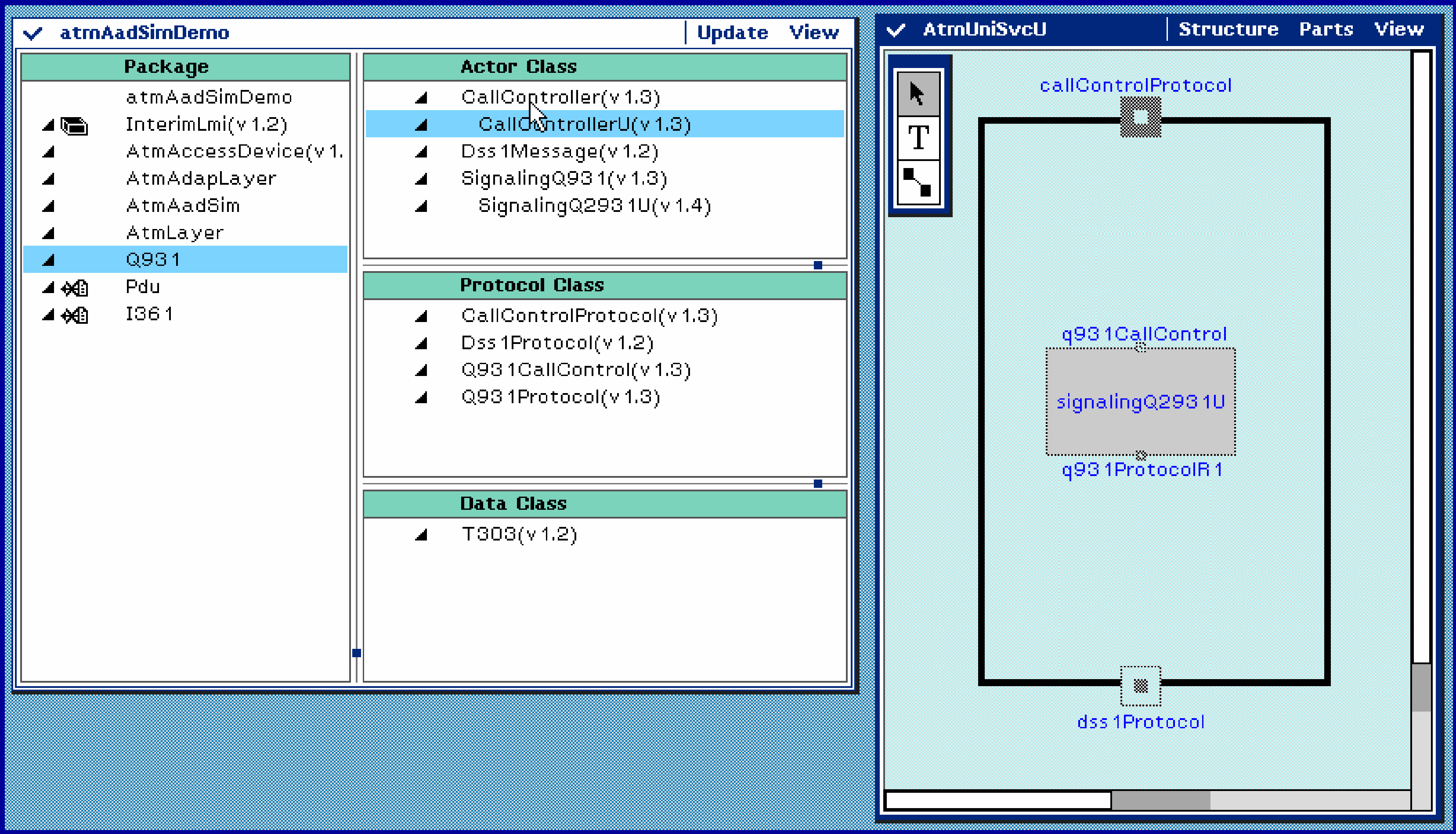
Example Environment: Meta-H



Example Environment: Aesop/PF



Example Environment: ObjecTime



Problems

- Building custom design environments is:
  - Expensive
  - Time consuming
  - Difficult
- Designers' tooling needs change as their understanding of the problem, domain, and target system evolves

Solution: *Armani*

- Support lightweight, incremental adaptation and customization of design environments
  - Factor out common infrastructure
  - Capture variable design expertise
  - Configure infrastructure with expertise

Generic Infrastructure

Custom Environment

Unclogging Bottlenecks

Task	Armani changes	Gain
Domain analysis	- Still requires domain understanding - …but provides expressive structure	**Small**
Creating schema and capturing expertise	- Armani defines schema and provides structure for capturing expertise declaratively	**Large**
(Re-) design, implement, integrate tools, and test environment	- Core infrastructure reused - Basic tooling generated from expertise description. - Still must implement rich tooling	**Huge**
Adapt and evolve environment	- Configurability and modularity greatly reduces evolution difficulty	**Large**

Thesis

- Claim 1:
  - It is possible to capture software architecture design expertise with a language and mechanisms for expressing *design vocabulary*, *design rules*, and *architectural styles*.
- Claim 2:
  - This captured design expertise can be used to rapidly and incrementally customize software architecture design environments.

Capturing Design Expertise

- Introduction and motivation
- Capturing design expertise
- Customizing design environments
- Validation
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Architectural Design Expertise

The concepts, models, and rules that skilled architects use when specifying, constructing, or analyzing a software architecture.

Armani provides a declarative language for capturing architecture design expertise

Capturing Design Expertise

- Design vocabulary
  - Building blocks for system designs
  - e.g. *client*, *web-server*, *database*, *pipe*, *RPC*
- Design rules
  - Invariants, heuristics, and analyses
  - e.g. "*Transaction rate must be >= 1000 tph*"
- Architectural styles
  - Package related vocabulary and design rules
  - e.g. *Client-server*, *pipe-filter*, *batch sequential*

Design Vocabulary Example

```
Component Type naïve-client = {

   Port Request = {
         Property protocol = rpc-client };

   Property request-rate : integer
      << default = 0; units = “rate-per-sec” >>;

   Invariant forall p in self.Ports |
                 (p.protocol = rpc-client);
   Invariant size(Ports) <= 5;
   Invariant request-rate >= 0;
   Heuristic request-rate <= 100;
}
```

Design Rule Example

```
System simpleCS = { …
    // simple rule requiring a primary server
    Invariant exists c : server in self.components |
                   c.isPrimaryServer == true;

    // simple performance heuristic
    Heuristic forall s : server in self.components |
                   s.transactionRate >= 100;

    // do not allow client-client connections
    Analysis no-peer-connections(sys : System) : boolean=
        forall c1, c2 in sys.components |
              connected(c1, c2) ->
                     !(declaresType(c1,clientT)
                     and declaresType(c2, clientT));
… };
```

Architectural Style Example

```
Style naïve-client-server-style = {
  // declare vocabulary
  Component Type naïve-client = {...};
  Component Type naïve-server = {...};
  ...
  // declare design analyses
  Analysis no-peer-connections(sys : System)
              : boolean = { ... };
  ...
  // declare style-wide design rules
  Invariant no-peer-connections(self);
  Heuristic forall s : server in self.components|
                s.transactionRate >= 100;
...
} // end style definition
```

Predicate-Based Expertise Capture

- (Most) expertise represented w/predicates
  - Simple type checking tests constraints
  - Predicates can be written over structure, properties, topology
- Clean, flexible approach to subtyping
- Excellent compositionality and modularity
- Predicates can apply to types *or* instances

Language Supports Approach

- Language provides environment foundation
  - Good representations ease environment impl.
  - Reconfigures environment “on the fly”
- Language provides flexible representation for
  - Types
  - Design rules
  - Design instances
- Constraint checking forms tool foundation

Customizing Design Environments

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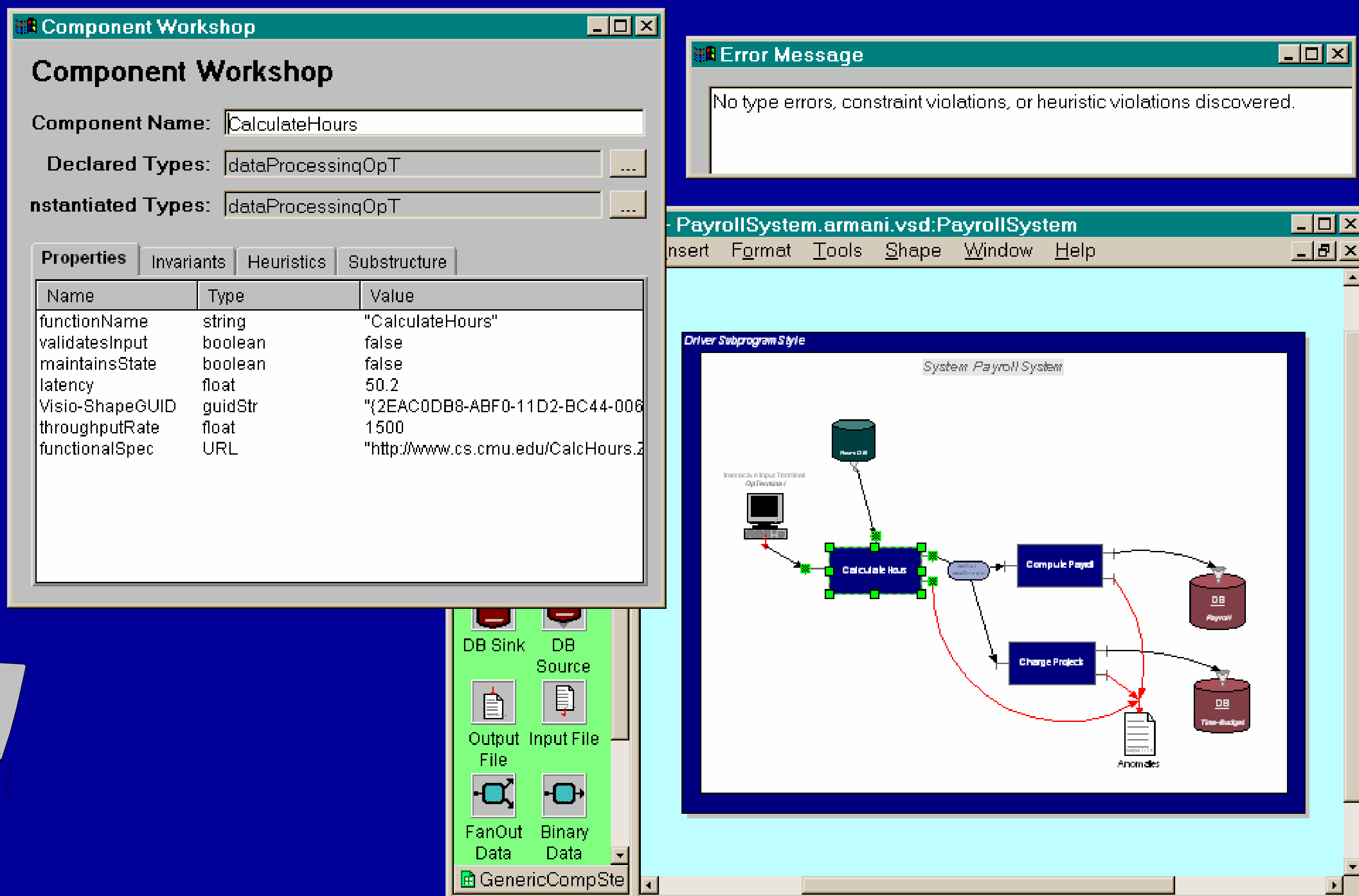
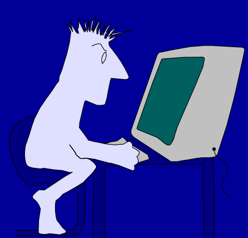
Example Environment: Armani

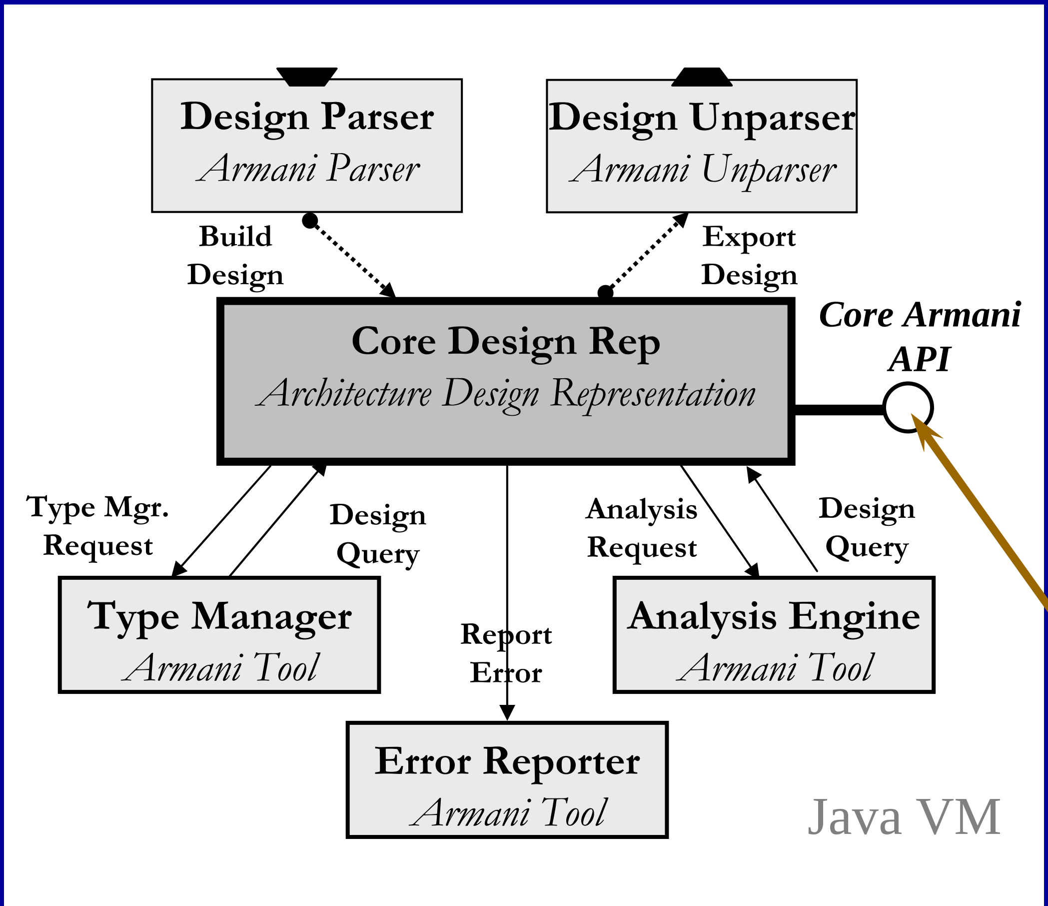




Customizing Design Environments

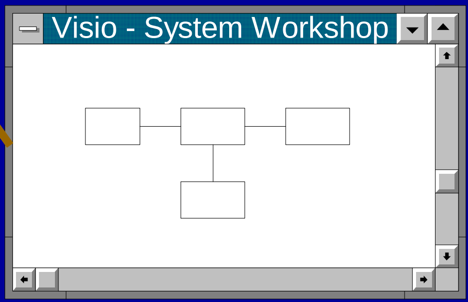
- Fundamental approach
  - Provide a fully-functional generic environment
  - Support fine- and coarse-grained customization
- Key design goals
  - Incremental effort leads to incremental payoff
  - Standard, common customizations are quick, easy, and incremental.
  - More complex customizations are possible
  - Leverage design language as much as possible

Core Environment Infrastructure



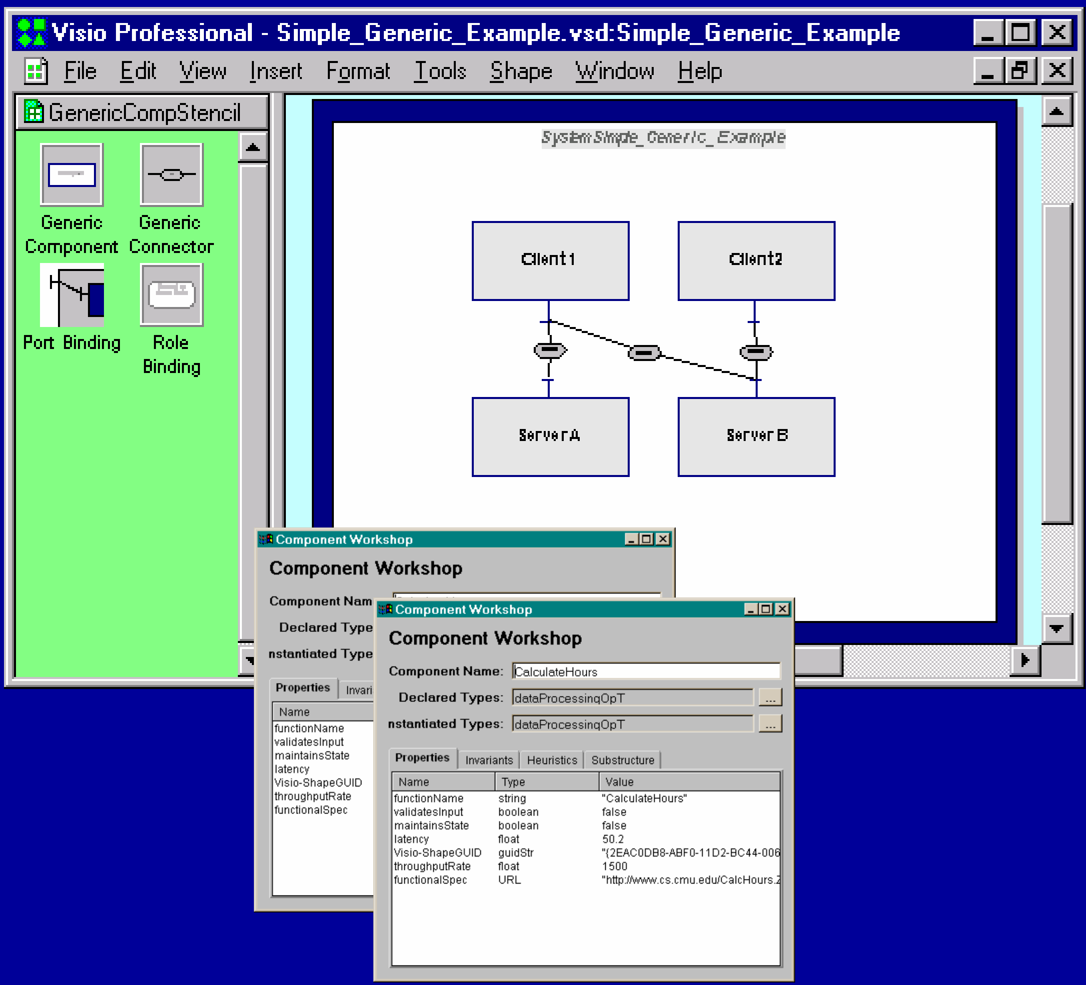
Generic elements:

- Design Rep w/API
- Parser & unparser
- Type checker
- Analysis Engine
- GUI



Visio-based GUI (external tool)

Generic Armani Environment

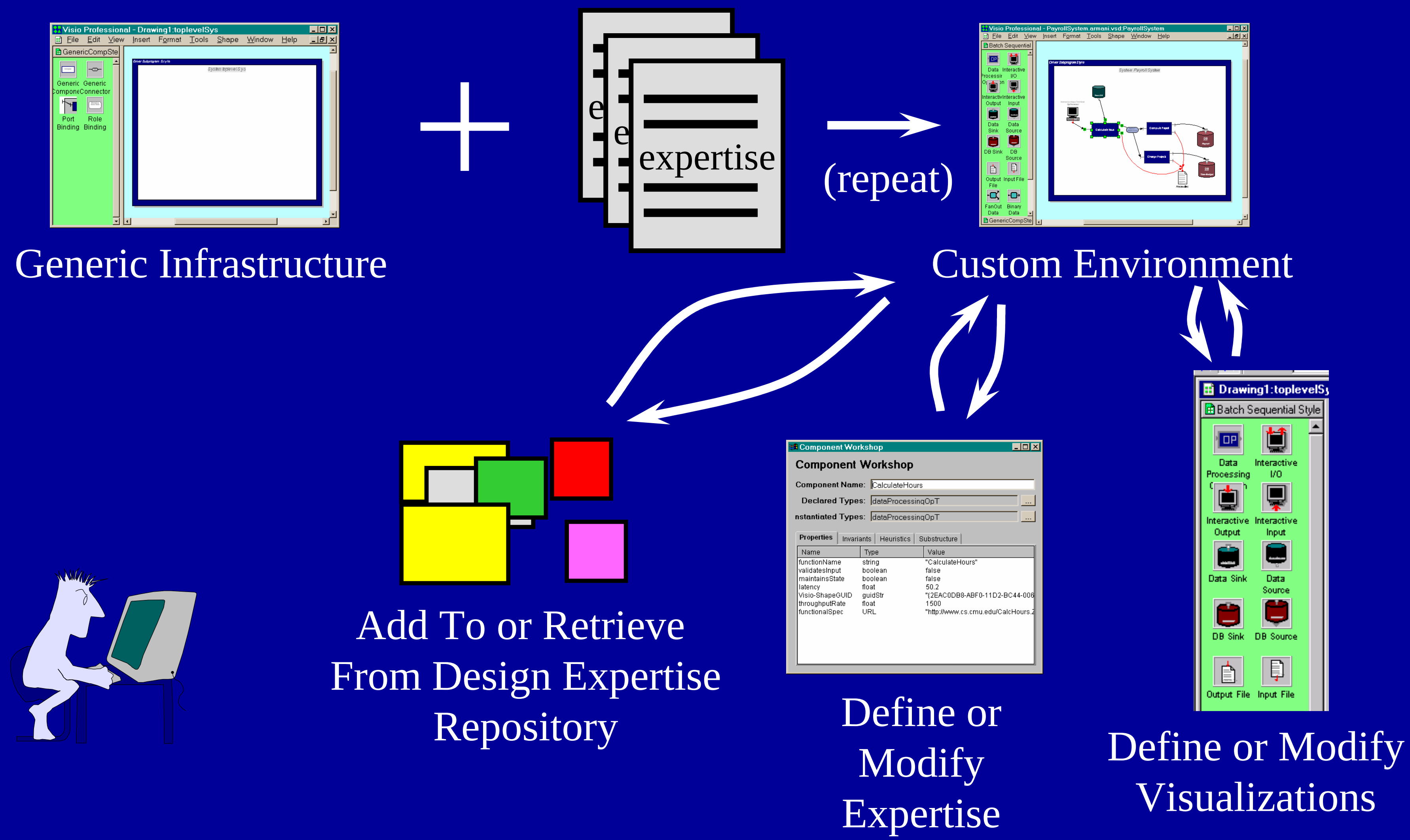


- Capabilities:
  - Define arch. specifications
  - Brings some rigor to box-and-line drawings
- Limitations
  - Limited semantics
  - Architect must build-up design concepts

Customization Techniques

- Fine-grained
  - Add or modify envt's stored design expertise
  - Customize graphical depictions within a GUI
- Coarse-grained
  - Integrate external tools
  - Completely replace GUI

Fine-Grained Customization



Coarse-Grained Customization

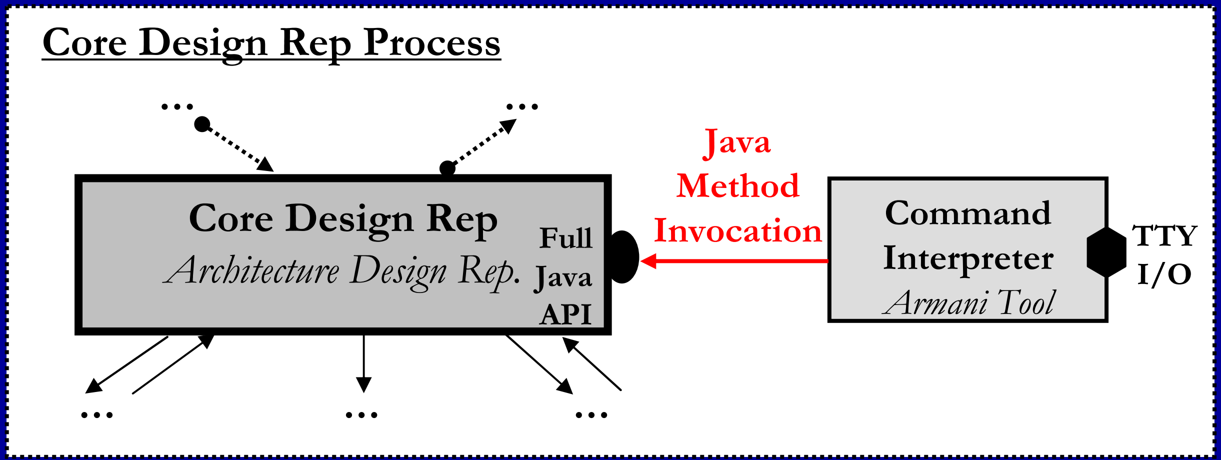
- Coarse-Grained ≈ external tool integration
- Some expertise is better captured with tools
  - When it *does something* to or with a design
  - When it is contained in legacy tools
  - When you have to specify *how* to evaluate it instead of just *what* to evaluate
- More effort, (potentially) more power

Integrated Tool Examples

- Multiple Armani user interfaces
- Performance analysis tool (Lockheed study)
- Change impact and configuration consistency analysis tools (MetaS study)
- Security and fault-tolerance analysis tool (DesignExpert study)
- Runtime architecture evolution checking (C2 study)

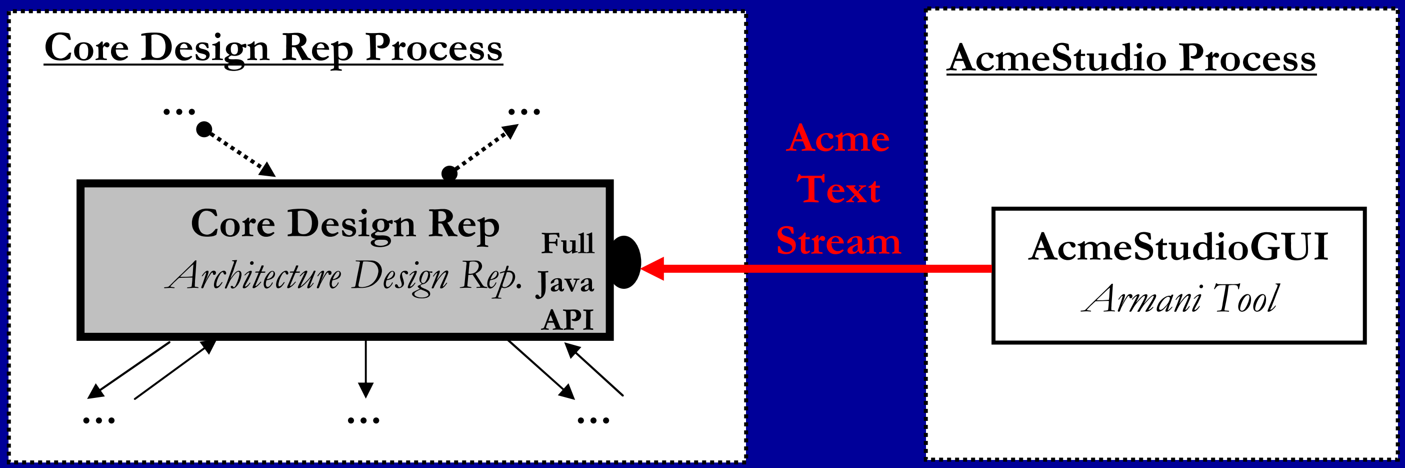
Integrating External Tools : UIs

- Command Line Interpreter
  - Scriptable textual interpreter
  - Integrated with direct Armani API calls
  - Simple procedure-call connector, same process



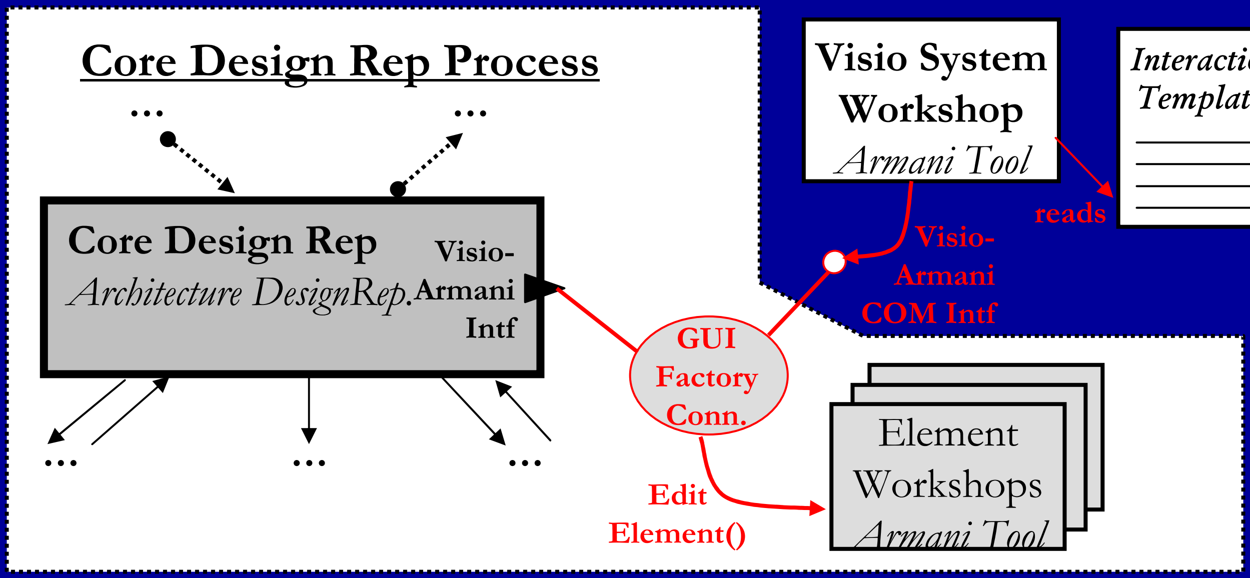
Integrating External Tools : UIs

- AcmeStudio GUI
  - Acme design environment front-end
  - Integrated via Acme text stream connector
  - Transport protocol encapsulated in connector



Integrating External Tools : UIs

- Visio-based Armani GUI
  - Highly configurable COTS-based front-end
  - Integrated using sophisticated COM-based intf.
  - Workshops generated by "factory" in connector



Design Environment Conclusions

- Environment demonstrates feasibility of configuring tools with design expertise
- Case studies will demonstrate utility...

- Environment leverages design language
- Support for both fine- and coarse-grained customization was critical

Validation

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Experimental Structure

- Basic approach: proof by existence
- Step 1: task analysis
  - Establish a baseline and find current bottlenecks
- Step 2: build multiple Armani environments
  - Demonstrate breadth, power, and incrementality
- Step 3: external case studies
  - Determine if others can use this technique

Step 1: Task Analysis Findings

- Current techniques require months or years of effort to build a custom environment
- Currently, most development time and effort is devoted to (re)building infrastructure
- If adaptability is not built in from the beginning, evolving an environment can be very difficult

Step 1: Task Analysis

Task	Approximate Time Required (in Engineer/Days, Weeks, Months, or Years)					
	Best Case		Average Case		Worst Case	
	Traditional	Armani	Traditional	Armani	Traditional	Armani
(1) Domain Analysis	Week	Week	Month	Weeks	Years	Months or Years
(2) Schema Capture	Days	Hours	Weeks	Days	Months	Weeks
(3) Design, implement, test and deploy environment	Months	Hours or Days	Months or Years	Days or Weeks	Years	Months
Cumulative time to initial deployment	**Months**	**Days**	**Months or Years**	**Weeks**	**Years or never**	**Months or never**
(4) Time required for environment updates and modifications.	Hours or Days	Minutes	Weeks or Months	Hours	Months	Weeks

Step 2: Build Test Environments

- Demonstrate breadth, power, incrementality
  - ***Breadth***: build environments for diverse styles
  - ***Power***: add significant design expertise to the environments
  - ***Incrementality***: adapt and extend environments
- Style selection
  - All case studies based on published style specs
  - At least one from each “Boxology” category

Step 2: Environments Built

Base Style	Specific Style	Total Hours of Effort	Types Defined	Design Rules Defined	Shapes Defined
Call and Return	Base Driver-Subprogram	**6.50**	18	3	7
	Driver-Subprogram w/DB	**4.00**	12	6	12
Data-Centric Repositories	Naïve client-server	**2.75**	7	3	5
	Three-Tier client-server	**3.50**	9	1	12
Hierarchical	Layered	**7.25**	11	3	6
Data Flow	Batch Sequential	**9.25**	29	3	14
Data Sharing	Armani Design Envt.	**4.50 (*)**	39	3	*
Interacting Processes	C2 rebuild in Armani	**8.00**	39	7	5

Step 2: Driver-Subprogram Style

Driver-Subprogram Style
Category: Call and Return

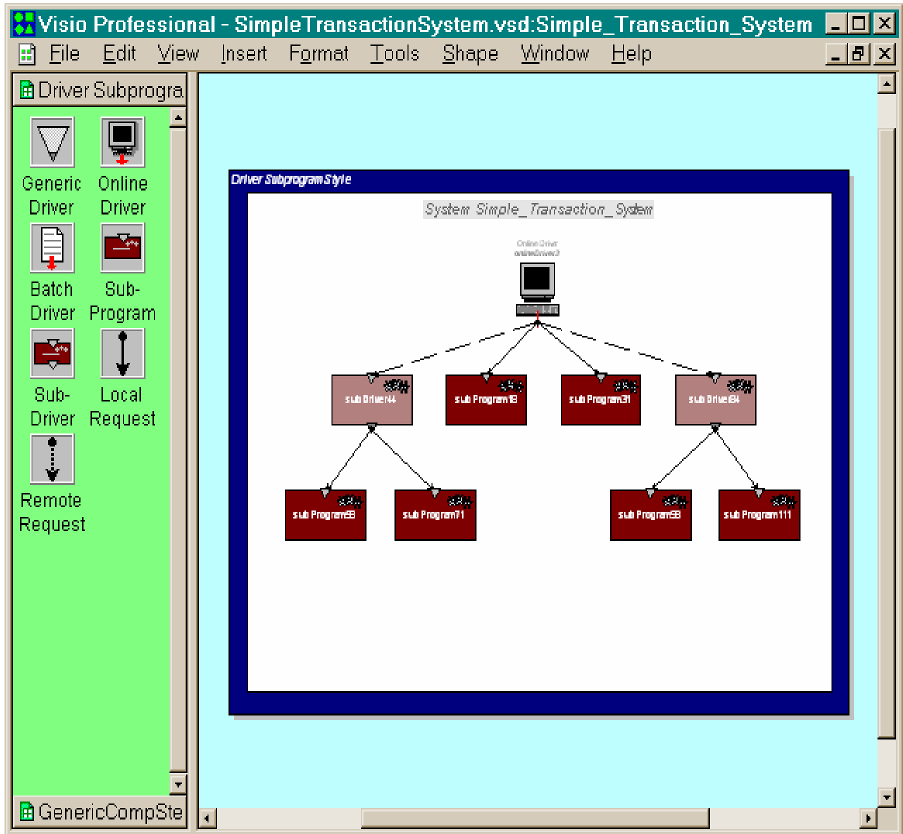
Semantics Statistics
Primary component types:
- Driver
- Subprogram
- Subdriver

Primary connector type:
- Processing Request

Sample design rule:
- A system has exactly one toplevel Driver component, but may have multiple Subdriver components.

New types defined: 18
Style-wide design rules: 3
Time to define: 3.5 hours
Lines of Armani code: 73

Environment Statistics
New shapes defined: 7
Customization time: 3 hours

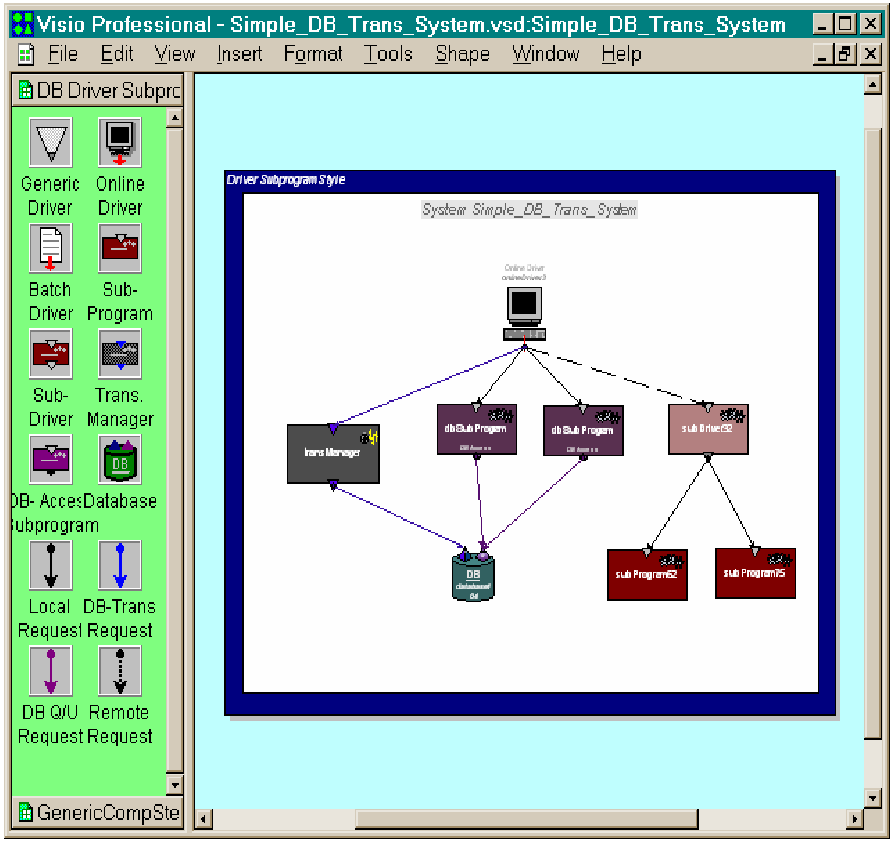


Step 2: DB-Driver Subprogram Style

DB-Driver-Subprogram Style
Category: Call and Return

Semantics Statistics
Extended component types:
- Transaction Manager
- Database
- DB Access SubProgram
Extended connector types:
- DB Query Update
- Transaction Request
Sample design rule:
- A system has exactly one Transaction Manager that must be connected to all databases.
New types defined: 12
Additional design rules: 6
Time to define: 2.0 hours
Lines of Armani code: 63

Environment Statistics
New shapes defined: 12
Customization time: 2 hours



Step 3: External Case Studies

- Qualitative “external” case studies asked:
  - Can other people use Armani effectively?
  - Powerful design expertise capture capabilities?
  - What aspects of Armani worked well?
  - What worked poorly?
- Case study selection criteria
  - Real architects or developers
  - Solving a real problem

Step 3: External Case Studies

- Conducted four external case studies:
  - – SEI's MetaS architectural style project
    - » Change impact and configuration consistency analysis
  - – UC Irvine C2-integration
    - » Run-time architecture evolution analysis
  - – Lockheed Martin/EDCS
    - » Built environment to model and analyze GTN
    - » Integrated performance analysis tool
  - – KeySoftware's "DesignExpert" tool
    - » Developed analyses for reliability and fault-tolerance

Step 3: Case Study Observations

- Can other people use Armani effectively?
  - Yes.

- Powerful design expertise capture?
  - Yes.
  - Case studies spanned broad variety of expertise
  - Case study tools solved real design problems

Step 3: Case Study Observations

- What aspects of Armani worked well?
  - Core concepts are flexible and powerful
  - Design representation and checking infrastructure more valuable than GUI
- What did not work so well?
  - Declarative design language requires reorientation of thought process
  - Building complex analysis and generation tooling still requires significant effort

Wrapup

- Introduction and motivation
- Capturing Architecture Design Expertise
- Customizing Design Environments
- Validation
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Contributions

- A technique for rapidly developing custom software architecture design environments
- A design language that captures both design expertise and architectural instances
- A reference architecture for highly configurable design environments
- A set of case studies that illustrate how to use the technique, language, and environment effectively

Related Work

- Aesop and Acme
- Architecture Description Languages (ADLs)
- Configurable programming environments
  - esp. Gandalf and The Synthesizer Generator
- Design patterns
- Formal specification languages (esp. PVS)
- Constraint-based prog. tools and languages
- DSSA

Future Work

- Generalized reconfiguration strategies
- Integration with full lifecycle processes
- Guidance in selecting styles and expertise
- Discovering new uses for the tools

Conclusions

- The Armani approach to capturing design expertise and incrementally configuring design environments works.
- The Armani conceptual framework can capture a significant range of interesting architectural design expertise.
- Predicate types are a useful abstraction for capturing and composing design expertise

The End

Robert T. Monroe
Carnegie Mellon University

Predicate Composition

```
Type FastT = {
  Prop. latency = …
  Prop. throughput = ...
  Invariant latency < …
  Invariant throughput >…
}
```

```
Type DatabaseT = {
  Prop. schema = …
  Prop. transRate = …
  Prop. multiThreaded = ...
}
```

```
Type TransactionalT = {
  Prop. transProtocol = …
  Prop. rollbackPolicy = ...
  Invariant (transProtocol
     != “”)
}
```

subtypes

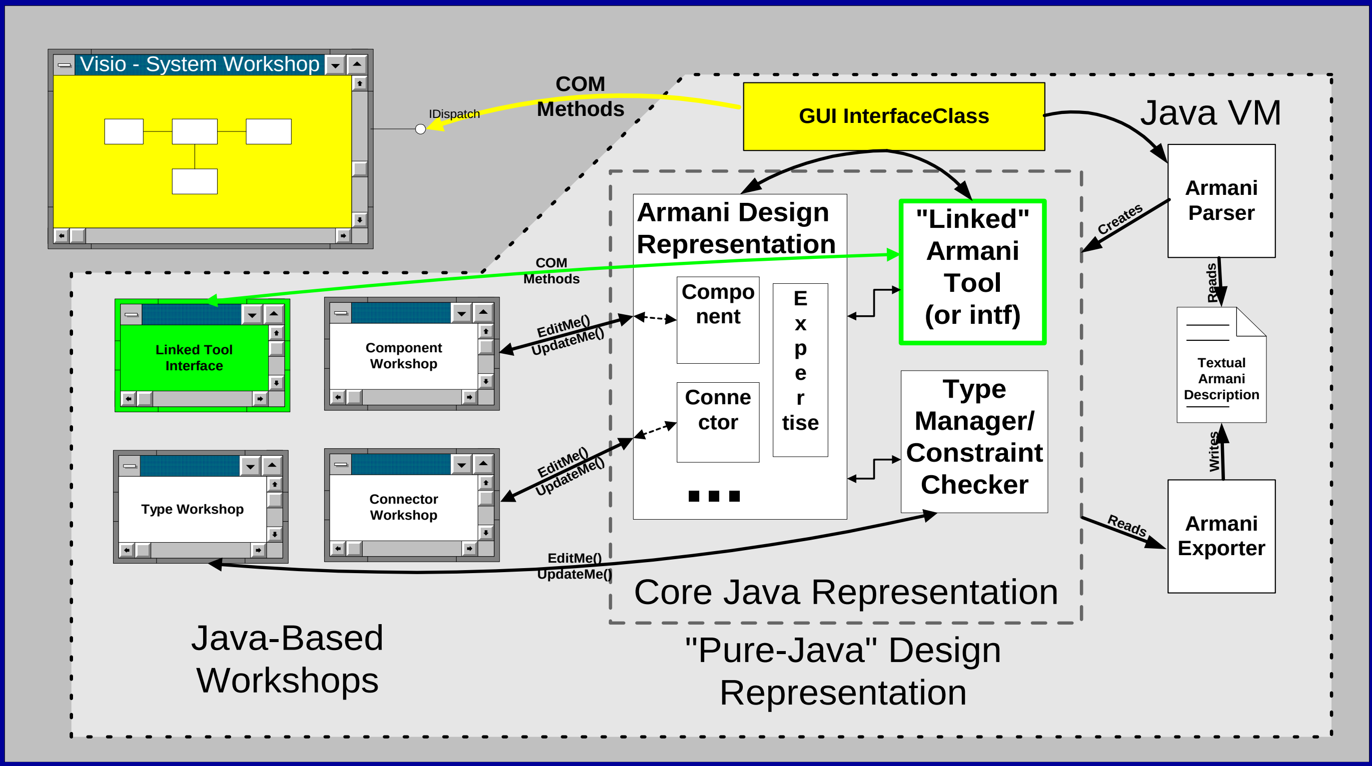
```
Type FastTransDatabaseT = {
  Prop. schema = …
  Prop. transRate = …
  Prop. multiThreaded = …
  Prop. latency = …
  Prop. transProtocol = ...
   ...
}
```

Standard Customization Process

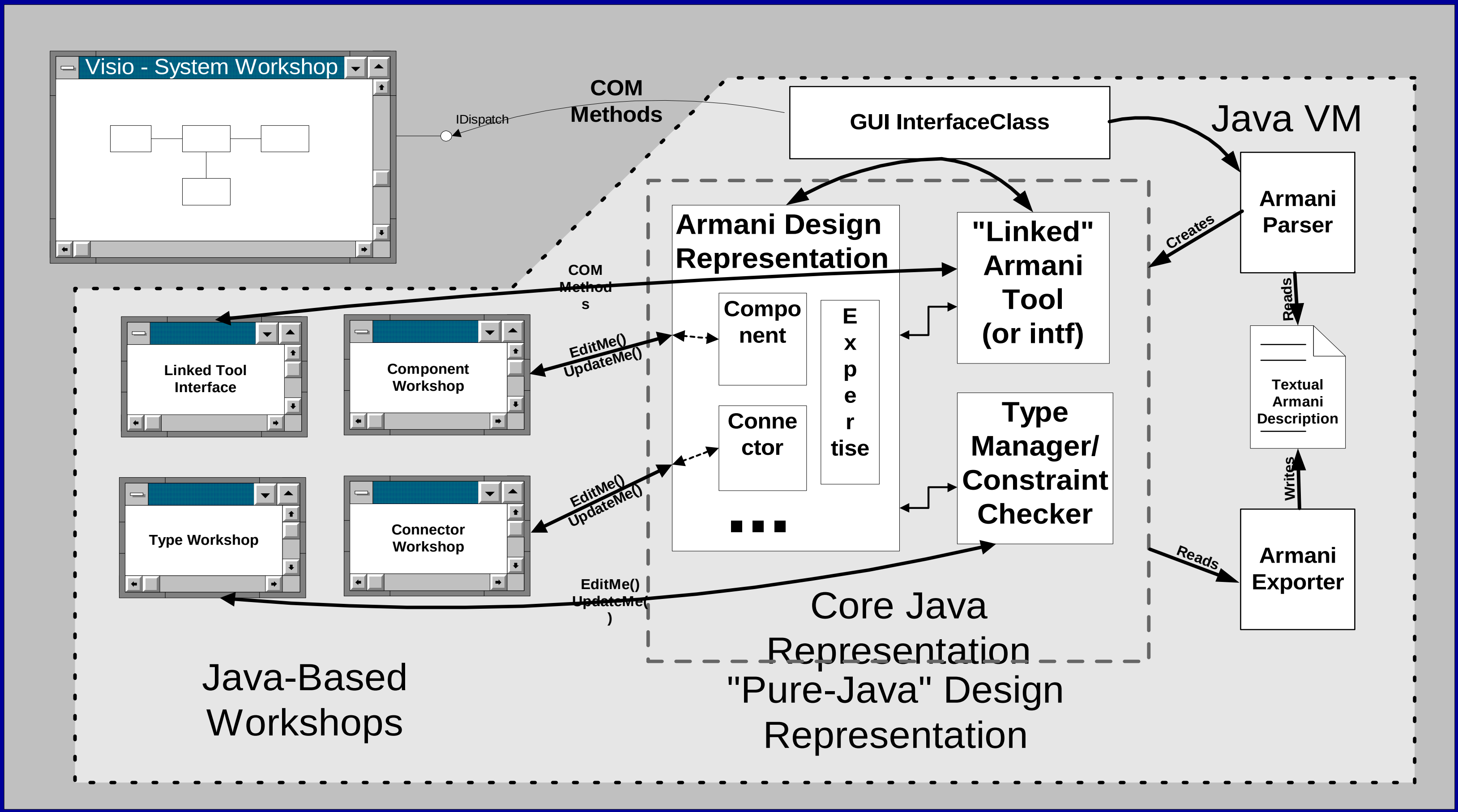
- Load design expertise captured with Armani design language into generic envt.
- Create custom icons to represent new design elements (optional)
- Modify expertise as needed
- Repeat

Obsolesced slide...

- Tools manipulate Armani designs through a programmatic API. (In or out of Java VM)



Armani Environment Architecture



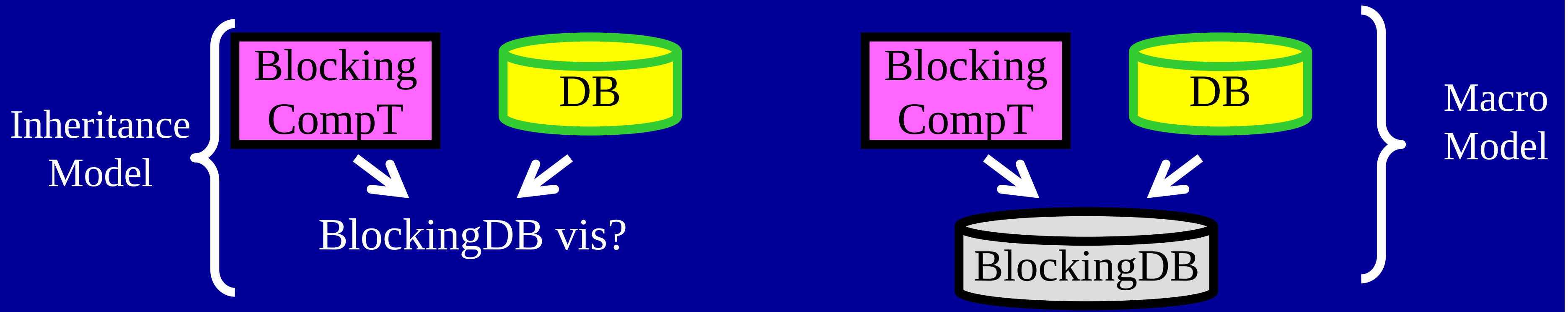
Generic Armani Environment

- The generic Armani environment provides:
  - API for manipulating design representation
  - Parser and unparser for design language
  - GUI
  - Design checker
  - Tool integration framework

Customizing Visualizations

- Different types of vocabulary elements require different visualizations
- Visio,™ used as the generic GUI front end, handles visualization specialization
- GUI Front-end is just another tool
  - It can be exchanged for a different front-end
  - Visualizations are highly independent of underlying semantic representation

Customizing Visualizations



- Challenge: Visualization semantics don’t work compose like architectural semantics

- Solution:
  – Associate visualizations with “templates” or “macros” instead of types.

Task Analysis - State of Practice

Task	Approximate Time Required		
	Best Case	**Average Case**	**Worst Case**
(1) Domain Analysis	Week	Month(s)	Year(s)
(2) Schema Capture	Days	Weeks	Months
(3) Design, implement, test and deploy environment	Month(s)	Months or Years	Years or until project cancellation
Cumulative time to initial deployment	**Months**	**Months or Years**	**Years or until project cancellation**
(4) Time required for environment updates and modifications.	Hours or Days	Months	Months

Creating a Design Environment

- Creating a custom environment requires ...
  - Domain analysis
  - Create schema for designs and design expertise
  - Design, implement, test, and deploy envt.
  - Modify and evolve environment as needed

Integrating External Tools : UIs

- Armani UI implemented as external tool
- Three integration connector types provided:
  - *Direct Java API call* for Java-based tools that run in the same process space as the Armani core infrastructure
  - *Acme text stream* for Acme-compliant tools
  - *Custom COM interfaces* for arbitrary external tool integration.
    - » Builds tool-specific, semantically rich, interfaces on top of the generic Armani Java interfaces