A Case Study in Incremental Architecture-Based Re-engineering of a Legacy Application

Marwan Abi-Antoun
Institute for Software Research Intl (ISRI)
Carnegie Mellon University
mabianto@cs.cmu.edu

Wesley Coelho
Department of Computer Science
University of British Columbia
coelho@cs.ubc.ca

With contributions by Jonathan Aldrich

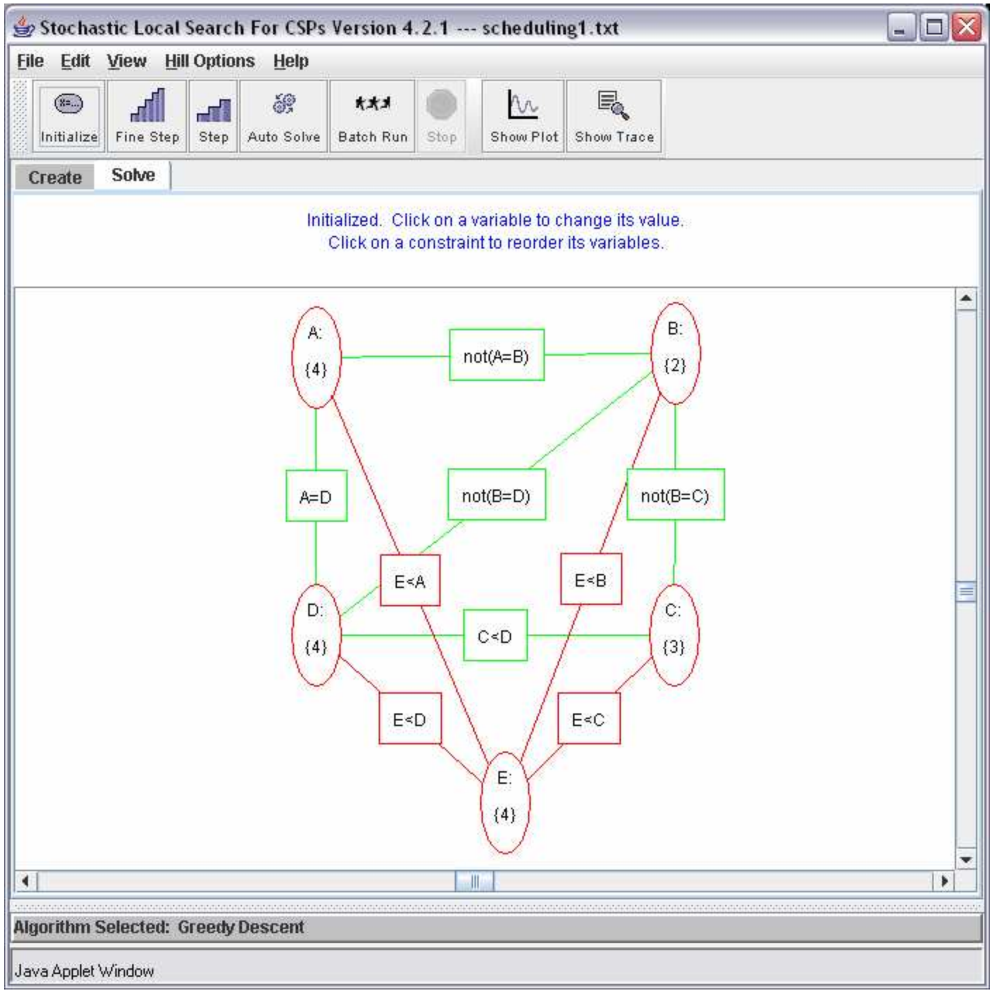
Software loses structure over time

- External documentation often out of date
- Developers rarely consult external documentation (if it exists)
- Developers unaware of architectural intent not described in code
- Developers introduce violations
- Architectural violations lead to
  - Brittleness,
  - Inadaptability, …

The case study subject system

- No external documentation
- Developer turnover
- Junior developers
- Evolved over several years
- Violations of the architecture
  - Lack of coherence and clarity of form
- Representative of legacy applications
  - Without careful maintenance and evolution

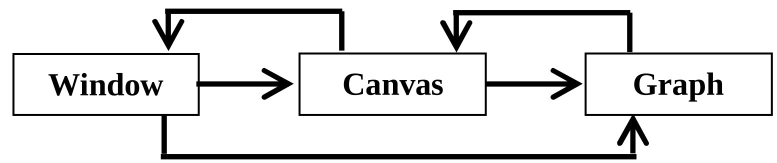
Case Study Application: HillClimber



- Graphically demonstrates AI algorithms
- Created and maintained by undergraduate interns
- Over 16,000 lines of code in 80 classes
- Large enough to exhibit complex design issues

HillClimber's architecture over time

Shared Framework



HillClimber: Today

- Part of a collection of applications using a shared framework
- Evidence of loss of structure, e.g.:
  - *Window* component requiring services from *Graph* component is a violation
  - Components provide services to or require services from most other components
  - Complex communication patterns

Goal of the case study

- One-time refactoring is temporary
- Loss of architectural information is a key contributor to architectural violations
- Address a root cause of violations
  - Specify the architecture in the code directly
- Re-engineer the implementation
  - To closely match idealized architecture
  - In a form that may prevent future architectural violations

Specify architecture in code

- ArchJava
  - Extension of Java programming language
  - Backwards compatibility critical for re-engineering
- Architecture specified in code
  - Components, Ports, Connections, …
- Enforces **communication integrity**
  - Two components can communicate only if they are connected in the architecture
- Extract as-implemented C&C view

ArchJava Example

```
public component class HillEngine {
```

```
public component class HillEngine{
```

```
    requires boolean isInline();
    ... }
```

```
public port engine{
        provides void setDelay(int dt);
        provides int getDelay();
}
```

```
    ...
```

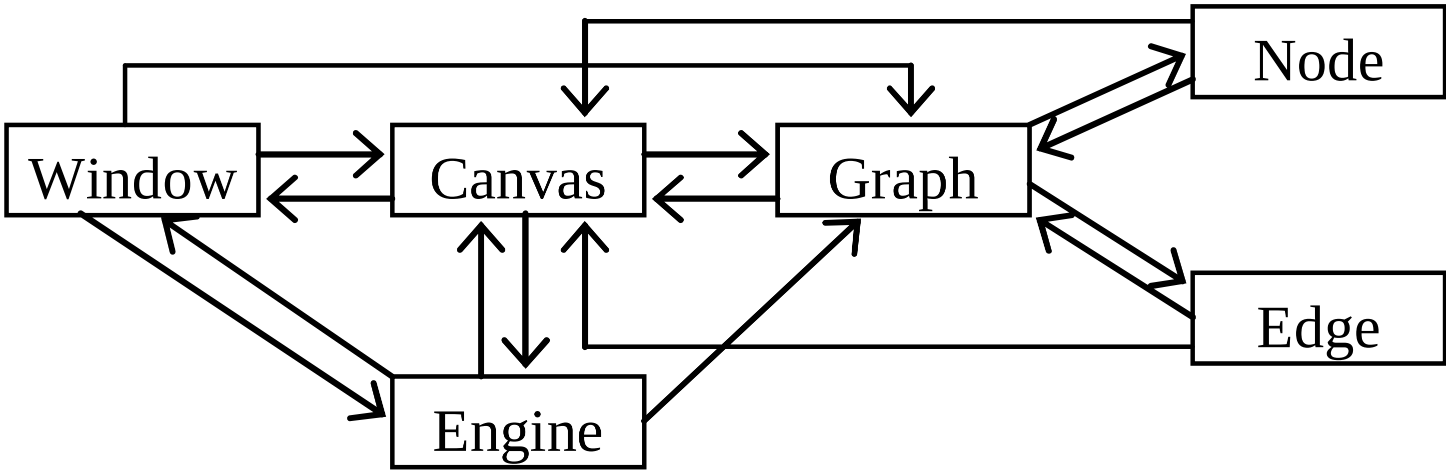
```
connect engine, graph.engine;
```

```
    public HillEngine() {
      ...
      // Note: Do most of initialization in init()
    }
    public void init() {
      ...
    }
    public void step() {
      ...
      if (!canvas.isInline() ) {
           window.setButtonsSolved(true);
      ...
}
```

Architecture-based re-engineering

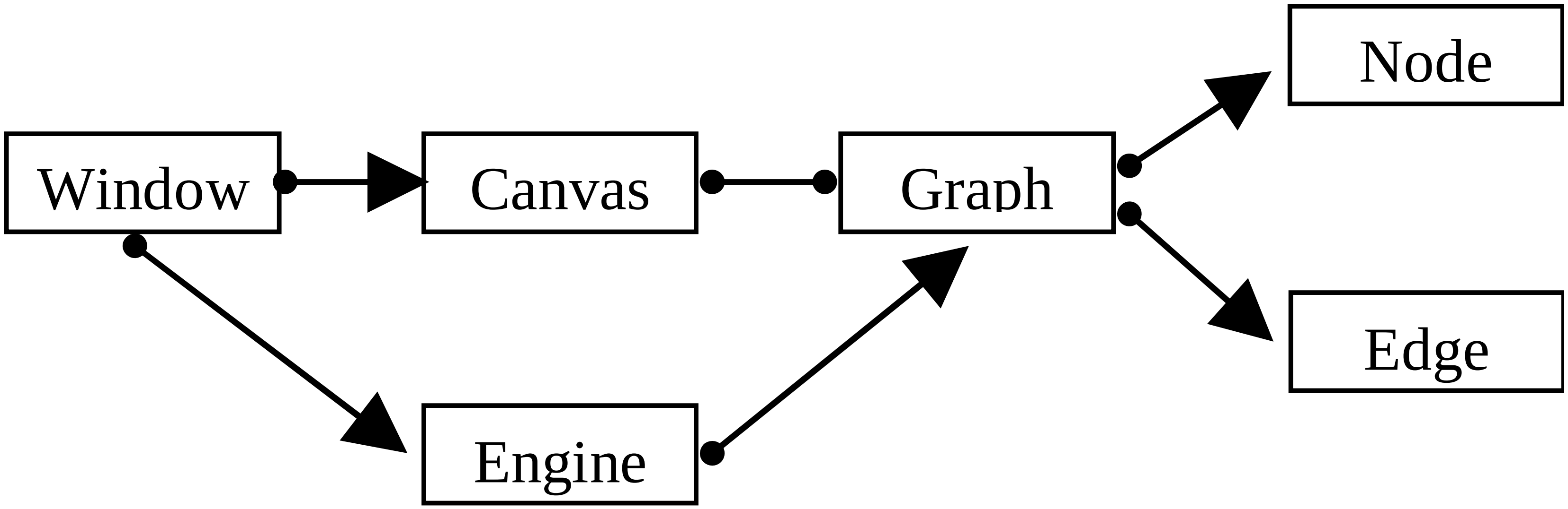
1. Identify the source architecture
2. Identify the target architecture
3. Refactor the original program (in Java)
4. Re-engineer to ArchJava
5. Check against the target architecture

Step 1: Identify the source architecture



- Extracted using manual call-graph analysis
- Changes to one component affect several components
- Communication between components follows a nearly arbitrary pattern

Step 2: Identify the target architecture



- Uses same architectural decomposition to avoid significant rework
- Less complex communication patterns
  - Graph and Engine independent of UI

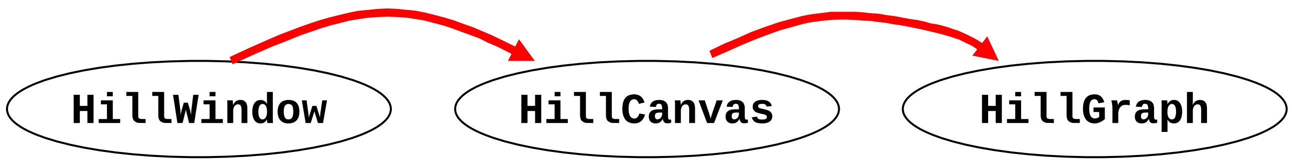
Step 3: Refactor the original program

- Avoid enforcing degraded architecture
- Re-engineer incrementally, while maintaining a running system
- Prepare the system for re-engineering
  - ArchJava imposes constraints on implementation
  - Limited tool support for refactoring once in ArchJava
- May involve significant restructuring if current implementation does not match the target architecture well

Refactoring Examples

- Rename identifiers for comprehension
  - ArchJava code ≡ architectural documentation
- Encapsulate fields
  - Required for communication integrity
- Remove “navigation code”
  - Code that traverses a series of object links before calling a method on the final object

Example: Remove Navigation Code




```
getCanvas().getGraph().setLineWidth(...)
```

- Symptom of misplaced behavior that
  - "Do not talk to strangers" – Law of Demeter
- Illegal in ArchJava because it involves passing component references

Example: Refactoring HillEngine

```java
public class HillEngine {
  public HillCanvas canvas;
```

```java
public int delayTime = 100;
```

```java
          HillCanvas canvas) {
    this.graph = graph;
    this.canvas = canvas;
    // Default heuristics
    stepCount = 0;
    searchAlgs = new Search[8];
    searchAlgs[0] = new RandSearch(this);
    ...
  }
  public void step() {
  ...
```

```java
((HillWindow)canvas.parent).setButtonsSolved(true);
```

```java
  ...
  }
  ...
}
```

```java
private int delayTime = 100;

public int getDelayTime(){
      return delayTime;
}
```

```java
    searchAlgs = new Search[8];
    RandSearch randSearch = new RandSearch();

    // TODO: Convert this to connect stmt
    randSearch.setWindow(window);
    ...
  }
  public void setDt(int dt) { this.dt = dt;}

  public HillWindow getWindow(){return window; }
  public void setWindow(HillWindow window) {
          this.window = window; }

  public void step(){
```

```java
if( !canvas.isInline() )
      window.setButtonsSolved(true);
```

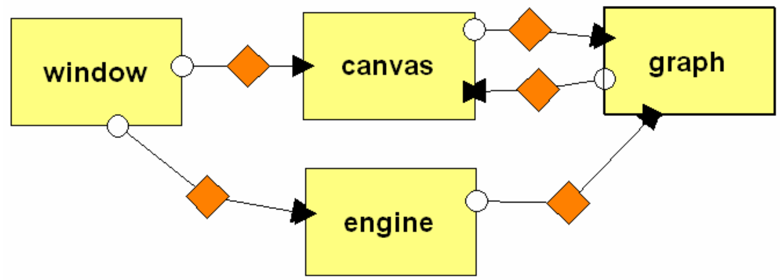
```java
    ...
  }
```

Before: Original Java `HillEngine` class. **After: Refactored HillEngine Java class.**

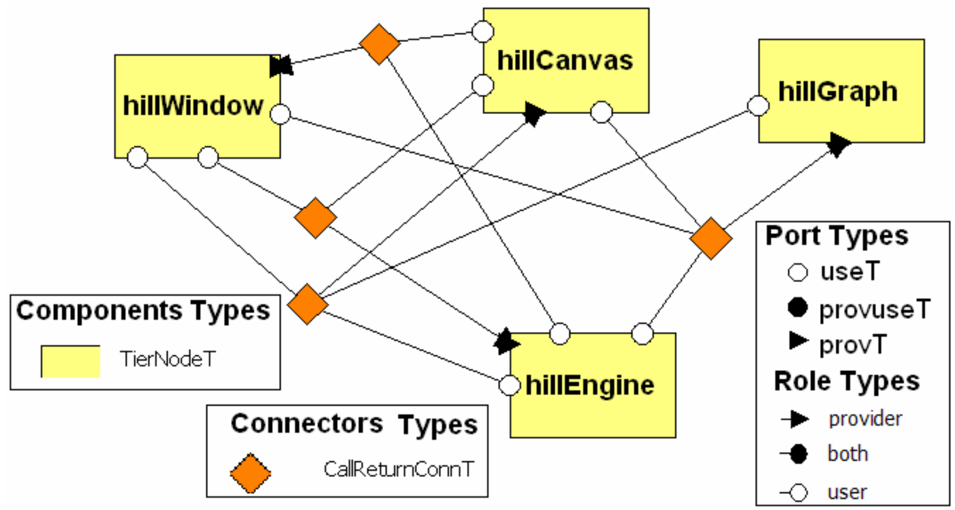
Step 4: Re-engineer to ArchJava

- Switch to ArchJava IDE
- Incrementally apply ArchJava constructs to describe and enforce architecture
  - Change class to component class
  - Convert instance variable to port
  - Change field link to connection
  - Convert program from reference-passing to establishing connections
    - Eliminate constructors or methods that take arguments of component type

Step 5: Check against target architecture



Target architecture



Automatically recovered intermediate architecture

- Automatically generated C&C snapshots
  - Visualize object sharing issues
  - Expose “unwanted” control flow
  - Visualize disconnected ports (statically)

Re-engineering result

- ArchJava effective in documenting and enforcing architectural structure
- Re-engineering effort involved
  - Approximately 2-3 days
- Learned several lessons
  - Hints for tool builders and language designers
  - Tradeoffs when using ArchJava

Hints for Tool Builders

- Keep it iterative
  - Inability to go back to pure Java and perform more refactoring was limiting
  - E.g., could not go back to pure Java to refactor missed unencapsulated fields
- Keep it incremental
  - “Legacy mode”: a component class can extend a “regular” class
  - Can add ports to non-component classes
  - Useful for maintaining a running version
  - Turning a class into a component class can suddenly generate many ArchJava compile errors

Hints for Tool Builders (Continued)

- Tolerate incompleteness
  - Required and provided port functionality must be completely specified
  - Temporarily disable checks for required/provided functionality to help maintain a running system
- Automate as much as possible
  - Many re-engineering tasks we performed could be automated
    - “Convert to component class” refactoring
  - Many of the tools we used were not satisfactory
  - Tools critical for dealing with larger code bases

Tradeoffs when using ArchJava

- Fundamental language design issue
  - Object-oriented programming and design patterns rely heavily on passing references
- Static checking vs. runtime checking
  - Runtime exceptions possible
  - Extensive testing of re-engineered program
- What we could not express
  - Specify port uni-directionality
  - Relax communication integrity
  - Full communication integrity
- Missing debugging and refactoring support

Case Study Limitations

- Need further study to answer
  - Is re-engineered program easier to understand and evolve?
  - Does documenting architectural intent help maintainers avoid architectural violations?
  - Will maintainers encounter expressiveness limitations of ArchJava?
- Current level of tool support for ArchJava limits its use in production

Related Work

Characteristic	This Case Study	Previous Case Studies	Legacy Applications
Programmers	Many	One	Many
Programmer Expertise	Novice	Expert	Junior
Turnover	High	Low	High
Lines of code	16 K	~ 8 K	10 K – 10+ M
Platform	Java	Java	Many
Middleware	None	None	Often

In summary

- Showed that a legacy system can be incrementally re-engineered to
  - Improve its structure
  - Document and enforce its architecture
- Presented a process for architecture-based re-engineering
- Provided hints for tool builders and language designers
- Already lead to improvements in ArchJava

Questions?