Connecting Software Architecture to Implementation: The Next 10 Years

Most Influential Paper of ICSE 2002 Award Talk
2012 International Conference on Software Engineering

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Thanks!

- We're honored that our paper has had an influence!
  - and the credit goes also to those who influenced and carried forward ArchJava (more in the talk)

- More broadly, our work is one piece of an important trend
  - Software architecture is becoming a valuable abstraction *in practice!*
  - Languages and tools relate code more directly to architecture
  - Tools verify architectural properties of software

- This talk
  - A bit about our ICSE'02 paper
  - How the trend linking architecture and code has grown since
  - What the future may hold

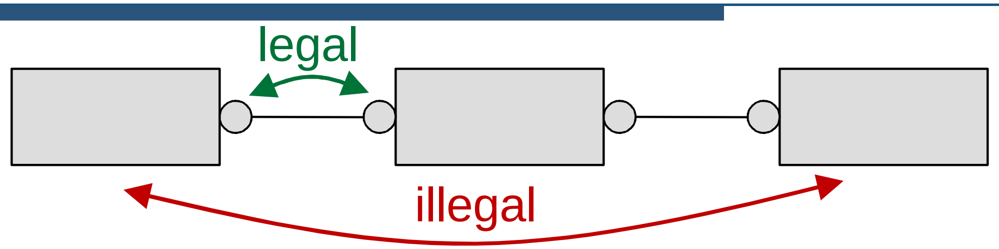
ICSE’02 Research Context

- Software architecture was an established concept
  - *The structure of the components of a program/system, their interrelationships, and principles and guidelines governing their design and evolution over time.* [Garlan & Perry, 1995]

- However, still maturing in practice
  - Last 3 stages of the Redwine-Riddle model [Shaw & Clements 2006]
    - internal/external exploration and enhancement, and popularization

- ICSE’02 Motivation and research question
  - Achieving the benefits of an architecture requires following it. Can we assure that code does so?

Architectural Conformance



- Prior work identified **communication integrity** as a key architectural conformance property

Interfaces [of a component] may communicate directly only if there is an architecture connection between the interfaces [Luckham & Vera 1995]

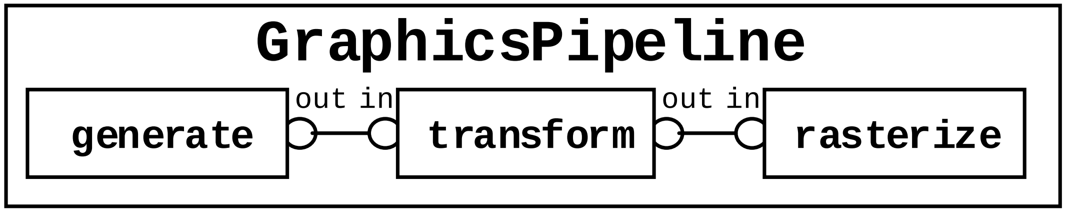
- Prior work on enforcing integrity
  - Theory of conformance [Moriconi et al., 1995]
  - Follow style guidelines [Luckham & Vera, 1995]
  - Use developer-directed analysis to extract (module) architecture [Murphy et al., 2001]

ArchJava's Approach

- Connect architecture with implementation by:
  - Embedding architecture in the programming language
    - Context: component and connector architecture, object-oriented code
  - Using a type system to ensure communication integrity

- Hypothesized benefits
  - **Traceability** – can easily answer architecture questions about code
  - **Communication integrity** – feasible to check
  - **Co-evolution** – architecture and code remain consistent
  - **Executable architecture** – architectural declarations are "live"
  - **Saliency** - architecture becomes an constant part of development

ArchJava Example: Graphics Pipeline



```
public component class Transform {
    public port in {
        provides void draw(Shape s);
    }
    public port out {
        requires void draw(Shape s);
    }
    void draw(Shape s) {
        currentTransform.apply(s);
        out.draw(s);
    }…
```

```
public component class GraphicsPipeline {
    protected Generate generate = ... ;
    protected Transform transform = ... ;
    protected Rasterize rasterize = ... ;
    connect generate.out, transform.in;
    connect transform.out, rasterize.in;
}
```

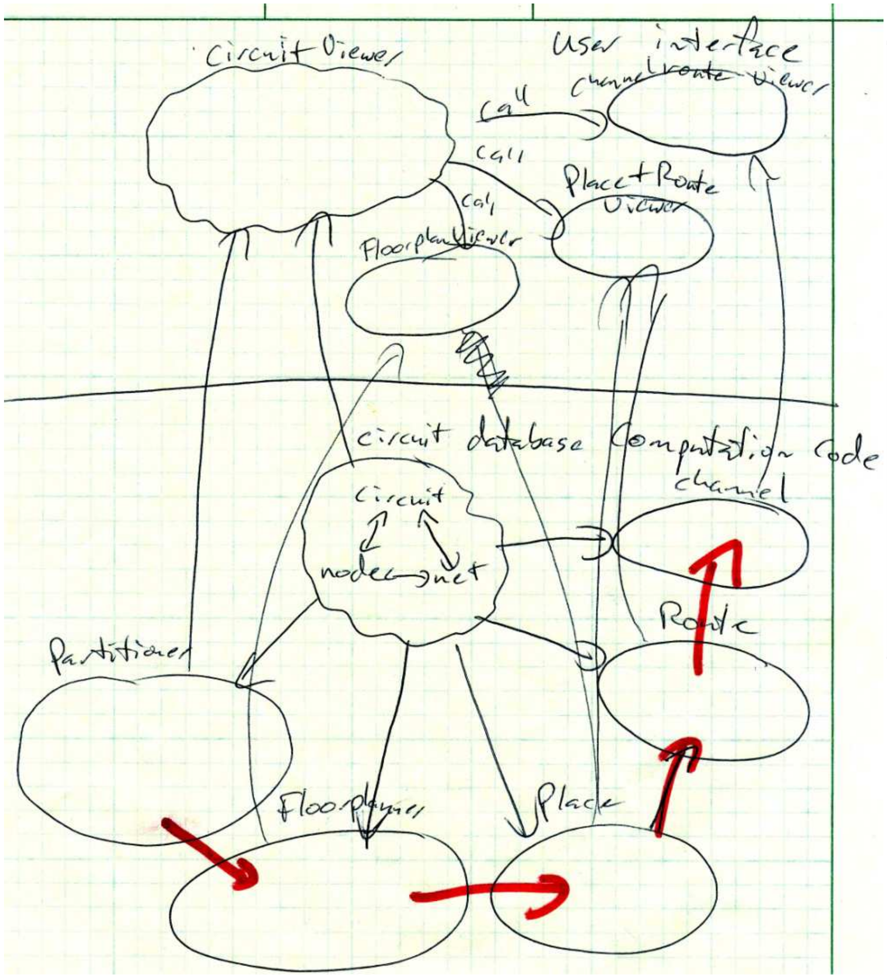
Architectural interfaces

Ordinary Java code

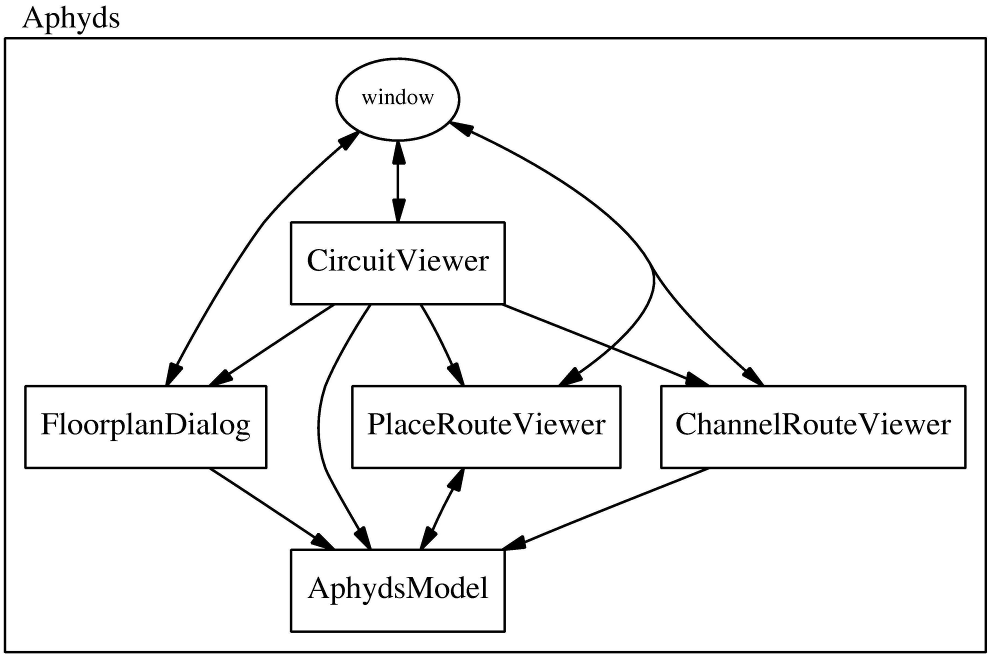
Connections link components

Typing rules prohibit passing component references to another component → cannot bypass connections

[Exploratory] Case Study with Aphyds



Architectural Drawing
by Developer



Architectural Visualization based
on ArchJava

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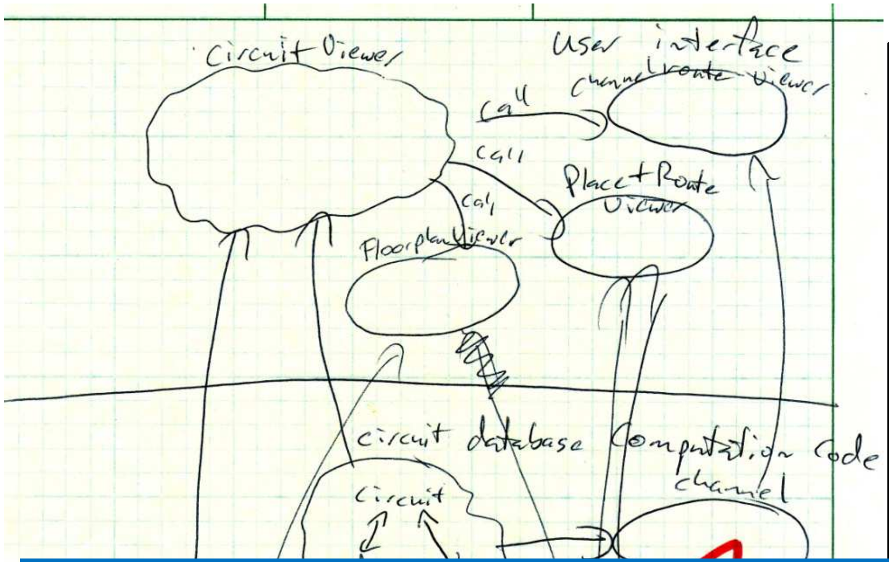
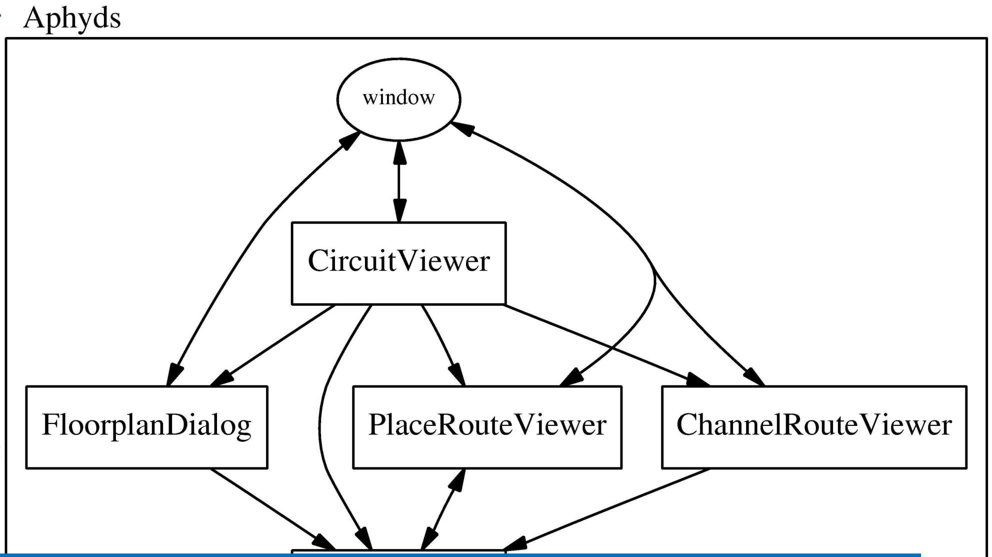




ed

- Some observations
  - Exploratory study generated interesting hypotheses (see paper)
  - The state of practice is still pretty informal (whiteboard diagrams)
    - Formality must provide value – connection to implementation is one way
  - Programming languages are (still) hard to evaluate
    - Large-scale, in-situ case studies or experiments not always realistic
    - Still worthy of exploration
    - Must find validation appropriate to claims

Why ArchJava Worked (as well as it did)

- Reaction from some: that's impossible!
  - Conformance of a program to an architecture is undecidable
  - Static analysis will have many false warnings due to abstraction
- True. We changed the game:
  - Developers integrate **design intent** into code
    - Using coding idioms that map to architecture
    - Types show how/why code conforms
    - Our goal: developers need not change macro-architecture to do this
  - This is (part of) making architecture more salient to developers
- This is a strength of a language-based approach
  - But also a weakness, creating difficulties for legacy code

The Last 10 Years: ArchJava

- ArchJava extensions
  - **Dynamic architectures** [ECOOP '02]
    - Inspired by Magee & Kramer, Dynamic Structure in Software Architectures, FSE '96
  - Communication integrity with **shared data** [WICSA '08]
    - Building on ownership [Noble et al. '98] and shared data connectors [Garlan and Shaw '93][Moriconi et al., '95]
  - Flexible **connector abstractions** [ECOOP '03]
    - Implement different connector semantics – both dynamics & typechecking
    - Inspired by and evaluated by Medvidovic et al.'s taxonomy [2000]

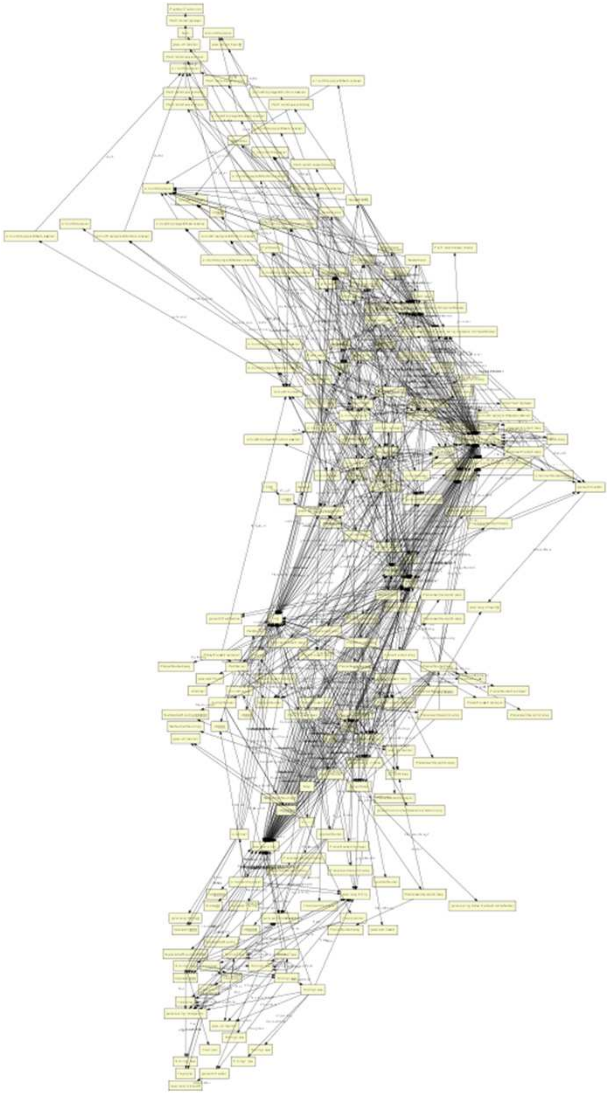
Connecting Architecture to Implementation

A selection of scientific work citing ArchJava:

- Generation & verification of **control systems** [Cassou et al, ICSE '11]
- **Synthesis** of architecturally correct code [Bagheri, ICSE '11]
- Automated **runtime validation** of architecture [Dong et al., '05]
- Architectural annotations in code for **Agile** [ICSE NIER '11]
- Architecture-driven **mobility** frameworks [Malek et al., '10]
- Component-oriented languages with first-class **connectors** [Chen et al '06]
- Checking architecture in legacy **scientific applications** [Woollard et al '09]

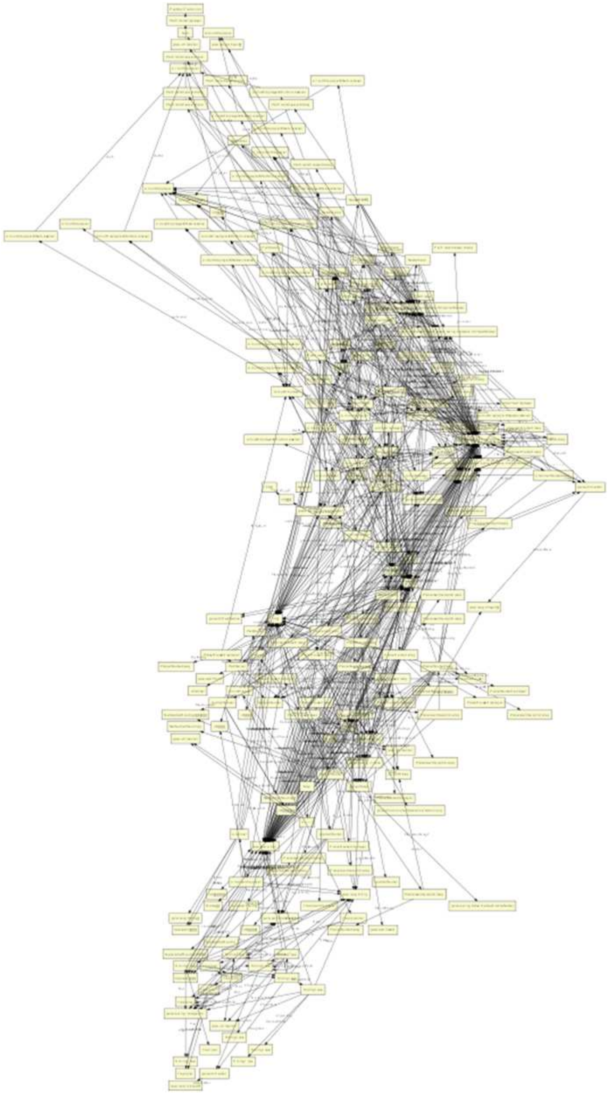
An example I've been involved in: the Scholia system

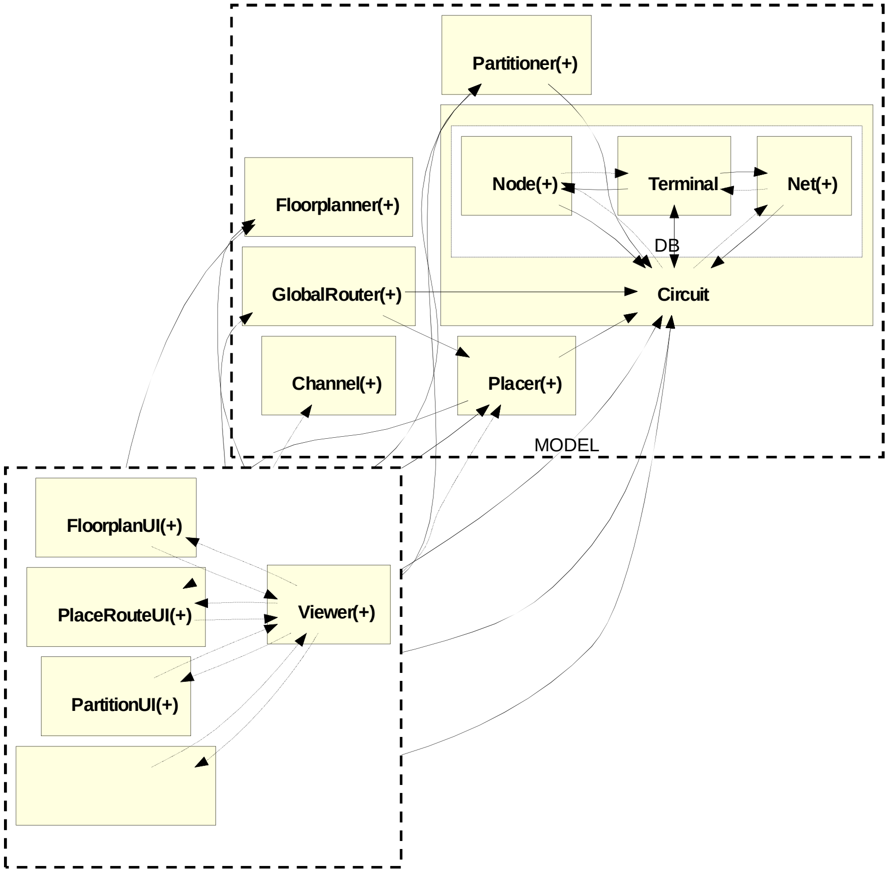
Motivation: Scalable Visualization of Object Graphs



Prior work: too many edges, hard to abstract

Using Design Intent to Extract Object Graphs



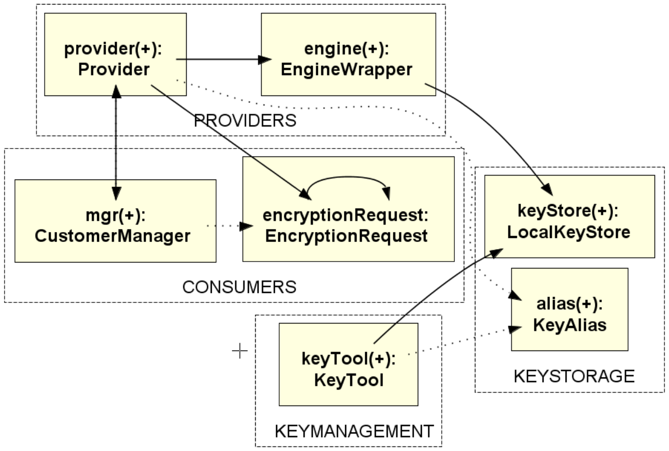


[Abi-Antoun & A, OOPSLA ‘09]

Declaring Architectural Intent

- Labeled groups
  - @Domain: Put in logical part of architecture

```
class Main {
                                        Provider provider;
                                         CustomerManager mgr;
                                           LocalKeyStore keyStore;
}
```



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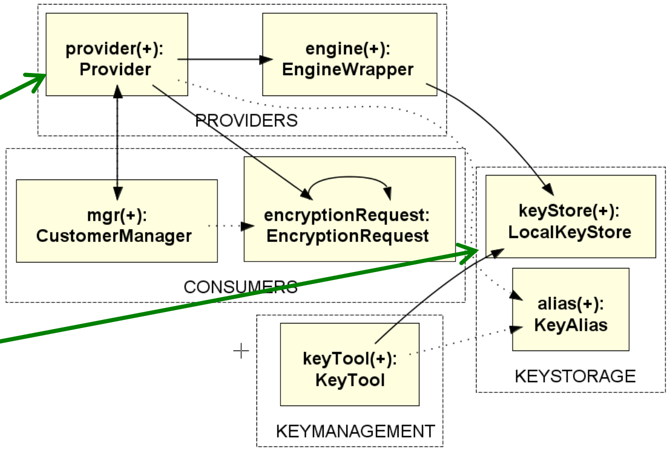

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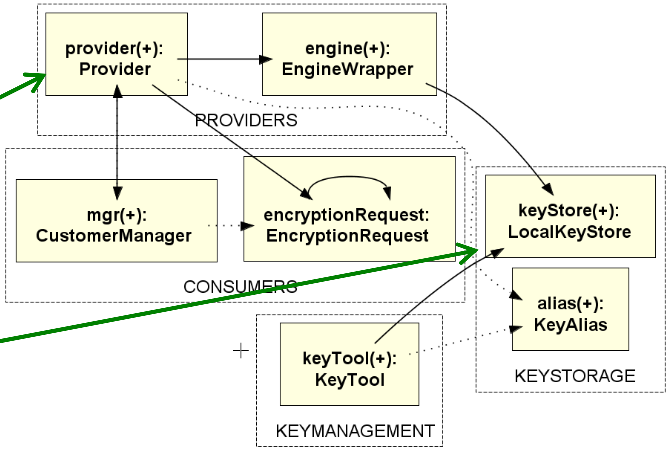
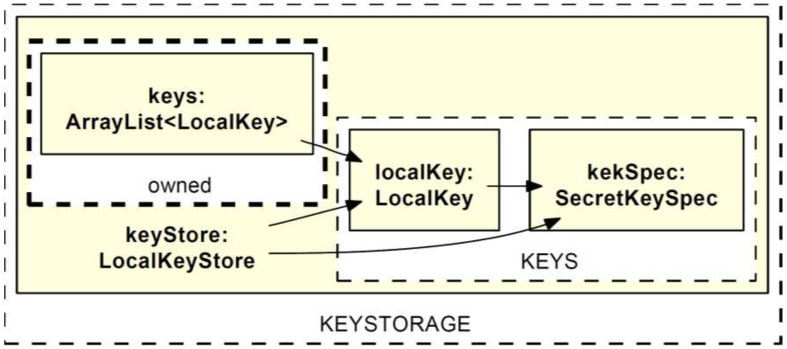


- Data structure encapsulation
  - OWNED: Hide data objects within high-level abstractions

```
class LocalKeyStore {
                    List<LocalKey> keys;
}
```



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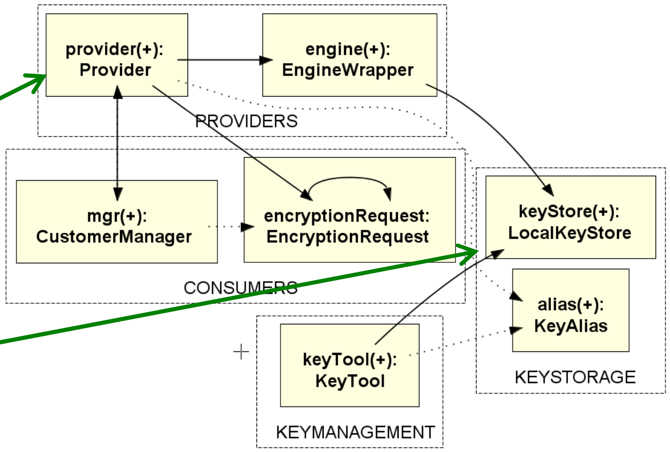

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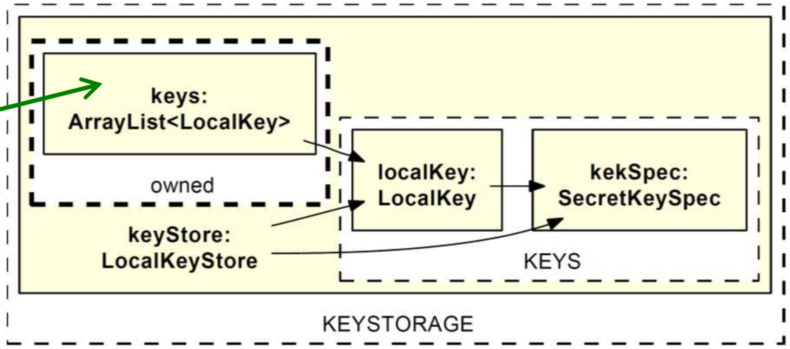
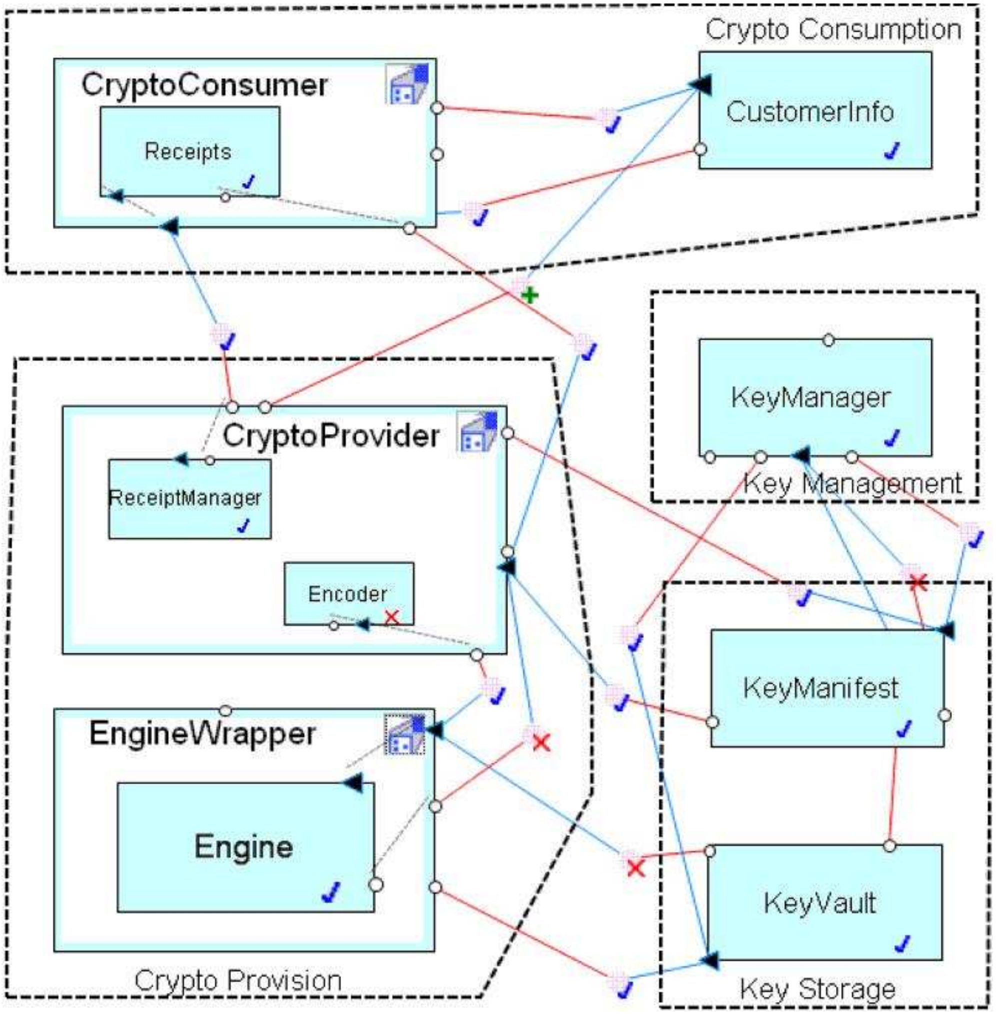
```
class LocalKeyStore {
    @Domain("OWNED<KEYS>") List<LocalKey> keys;
}
```



[Abi-Antoun & A, OOPSLA '09]

CryptoDB Case Study Results

- Architecture shows deltas
  - Intended vs. actual



[Abi-Antoun & Barnes, ASE ‘10]

Realizing the Vision: The Next 10 Years

- What new architecture-implementation connections can we make?

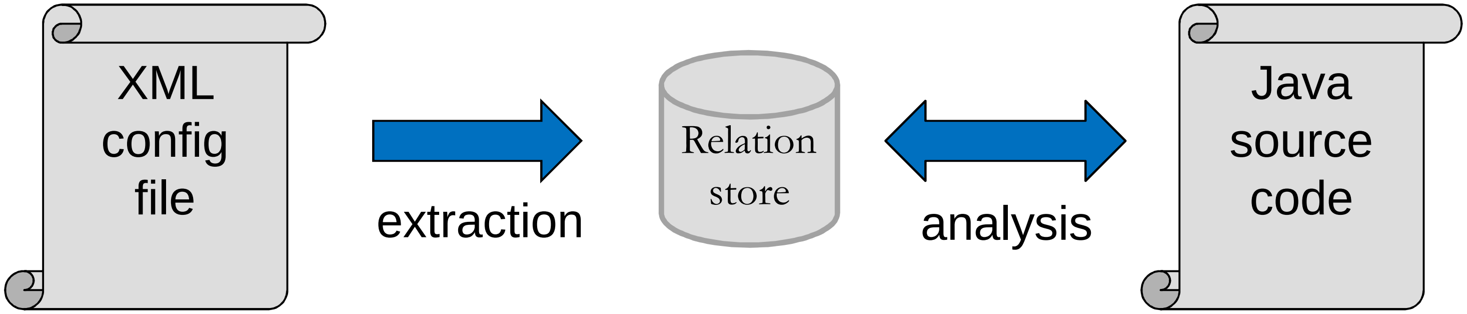
- How to make architecture part of everyday development?

Example: Architecture in Industry Frameworks

- Framework config files describe structure, properties
  - Web app frameworks (Spring, Rails)
    - Structure, security
  - Mobile frameworks (e.g. Android)
    - Event communication, UI flow, security

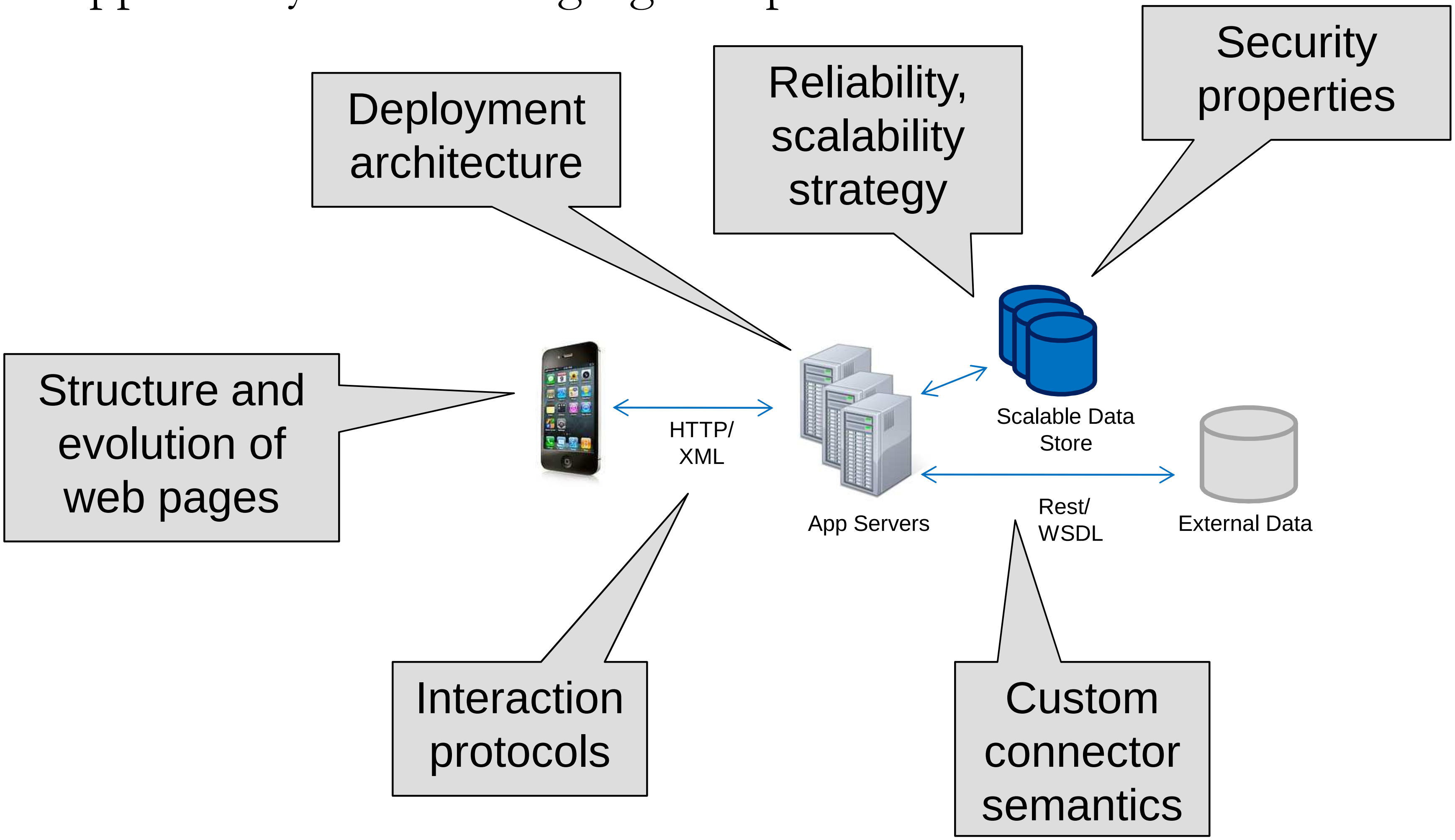
- Can we check consistency?
  - Framework-specific tools exist—do they generalize?

- FUSION tool at CMU/Cal Poly Pomona [C. Jaspan thesis, 2011]



Current Work: Mobile Web App Architecture

- Opportunity for new language adoption



Deployment architecture

Reliability, scalability strategy

Security properties

Structure and evolution of web pages

Interaction protocols

Custom connector semantics

Connecting Architecture to Implementation

- 10 years later, we have made progress
  - Making architectural verification more practical
  - Support for new kinds of synthesis, analysis
  - Domains such as mobility, scientific computing

- Many opportunities to have impact in practice!
  - Configuration as architecture
  - Emerging systems (web, mobile)
  - Exposing architecture in code

Acknowledgments

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  - Sangjin Han
  - Valentin Kostadinov
  - Nagi Nahas
  - Vibha Sazawal
  - Tony Tseng
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  - Jeff Barnes
  - Ciera Jaspan
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  - Cited above, and in the paper