Aspects at the crossroads of SE?!

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Where are we?

- Crosscutting as a fundamental problem of SE
- AOP has its place within SE:
  Integrated use of languages/frameworks/implementations

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What about the foundations of AOP?

- Formal methods in SE: large domain, uses generally rare but sometimes critical domains
- Do formal methods for aspects connect?
- (Real) uses of formal methods for AO?

Aspects at the crossroads

- **Is formal AO at the center of formal SE?**
  - Importance of the techniques/results?
  - Interest in the field?
- **Do we go/crawl/stumble in the right direction?**
  - Connect and apply to non-AO problems, methods, techniques

Where do we go?

- (Positive) Hypothesis:

  Foundations of AOP have come a long way . . .

  and go (slowly) towards use and application

- Some progression

From the specific	(semantics for individual mechanisms),
via the general	(integrated models),
to applications	(property enforcement and analysis)

Outline

1. The specific

- Language and weaving mechanisms
- Aspect categorizations
- Aspects for concurrent and distributed languages

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Influential and inspirational, building blocks, but few uses as such

Language mechanisms and properties

- Semantics for specific AO constructs
- First semantics for subsets of AspectJ
  [Wand et al.: TOPLAS'04]
- Data flow: `dflow[x, x'](p) bypassing [x](p)`
  [Masuhara, Kiczales: ASPLAS'03]
- Context-free tracecuts
  [Walker, Viggers: FSE'04]

Aspect categorizations

- Observers, assistants [Clifton, Leavens: FOAL'02]
- Augmentation, replacement . . . advice [Rinard et al. FSE'04]
  Definition in syntactic terms
- Spectative, regulative aspects [Katz, TAOS'06]
  Defined using temporal Logic
- Observers, confiners, aborters, weak intruders, selectors, regulators [Djoko Djoko, PEPM'08]
  Defines corresponding language classes that enforce properties

Concurrent and distributed applications

- Distributed AOP $\neq$ sequential AOP on distributed infrastructures
- Zoo of proposed language mechanisms: synchronization sets, operators for concurrent composition, remote pointcuts, (a)synchronous advice, distributed aspects with distributed state
- Proposed approaches focus on a small set of features
  - Encoding of sequential aspects in a CSP-like calculus [Andrews, Reflection'01]
  - Composition of superimpositions [Sihman and Katz, AOSD'02]
  - Composition of concurrent aspects [Douence et al., GPCE'06]

Outline

2. The general

More general models or usage ("aspects for SE")

- Modules, components and events
- Aspects and objects
- Distributed aspects

Modules, components and events

- Modules
  - Trade-off invasiveness and strong encapsulation
  - Modular property verification
- Components
  - Aspects for black, gray and white boxes
  - AO over interaction protocols
- Events
  - Explicit vs. implicit announcement
  - Integration with event-based approaches in SE

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Wide range of complementary models, clearly relevant to SE

Modular aspect definitions

Large variety of formal and semi-formal models

- Applicability conditions [Douence et al.: AOSD'04]: restrict aspect application by means of regular pointcuts
- Open modules [Aldrich: ECOOP'05]: advice only on external and exported calls
- Demeter interfaces [Skotiniotis et al.: ECOOP'06]: constraints on call graphs
- Aspect-aware interfaces [Kiczales, Mezini: ICSE'05]: full access but "external" pointcut specifications

Range from limited to farreaching invasiveness

Aspects and objects

- Integration (partially) obvious: use OO features if possible
  - Advice similar to method calls
  - (Some) pointcuts realized by advanced dispatch mechanisms
- Keep remaining features of AOP

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- **Few formal approaches**
- **What's essential to AOP?**

The A calculus: seamless AO-OO integration

Principles

- Essentiality criterion: relevance to type safety
  - Many mechanisms, e.g. pointcuts, are not
- Enable reuse using standard OO features
- Support large space of pointcut and advice mechanisms

The A calculus: integration of AO features

- Closures to replace advice incl. `proceed`: enables reuse

```
class C { int m1(int i, int j) { return i+j; }}
class D { void m2(int x, String s, int y) { System.out.println(x*y); }}
class A {
  int m((int,int)->int proceed, int a, int b) { return proceed(a+1,b-1); }
  around1: execution(int C.m1(int a, int b)) { return m(proceed,a,b); }
  around2: execution(void D.m2(int a, String s, int b)) {
      m((int a, int b => proceed(a,s,b); return 0),a,b); }
}
```

- Call/execution advice: static/dynamic closures
  - Type safety determines ordering of call/execution advice

The A calculus: support for mechanisms

- Rich pointcut languages through transformation and advice selection strategies
- Calculus parametrization support advice selection strategies
  - Ex.: flat login sessions

$$
\begin{aligned}
[\![f]\!]_{\langle \_,\mathrm{login}\rangle} &= \text{if } !f \text{ then} f = \mathrm{true} \\
\mathsf{getCAdvice}(f, \_, \_, \mathrm{v.login}, \_) &= \text{if } f \text{ then } \epsilon \text{ else } \bullet \\
\mathsf{getCAdvice}(f, \_, \_, \_.\mathrm{login}, \_) &= \bullet \\
\mathsf{getEAdvice}(\_, \_, \_, \_, \_) &= \bullet
\end{aligned}
$$

A general basis for distributed aspects

Aspect Join Calculus [Tabareau, AOSD'10]

- Objects, Concurrency, Distribution
- Remote pointcuts, distributed advice and aspects, migration
- Accommodates features of many proposed languages

  Ex.: cache replication

  $$\Vdash^{\varphi} \textsf{aspect } \mathit{bufferRepl} =$$
  $$\textsf{intercept} : \textsf{rule}(\mathit{buffer}.(\mathit{put}(n)\ \&\ \mathit{empty}())) \wedge \neg\, \textsf{host}(\varphi)$$
  $$\{\textsf{obj}\, b = \mathit{buffer}\ \textsf{init}\, b.\mathit{empty}()\ \textsf{in}(b.\mathit{put}(n)\ \&\ \textsf{proceed}(n))\}$$

- Translation into the standard join calculus: correctness proof of weaving

Outline

The connected and the applied

Connect and apply to non-AO problems

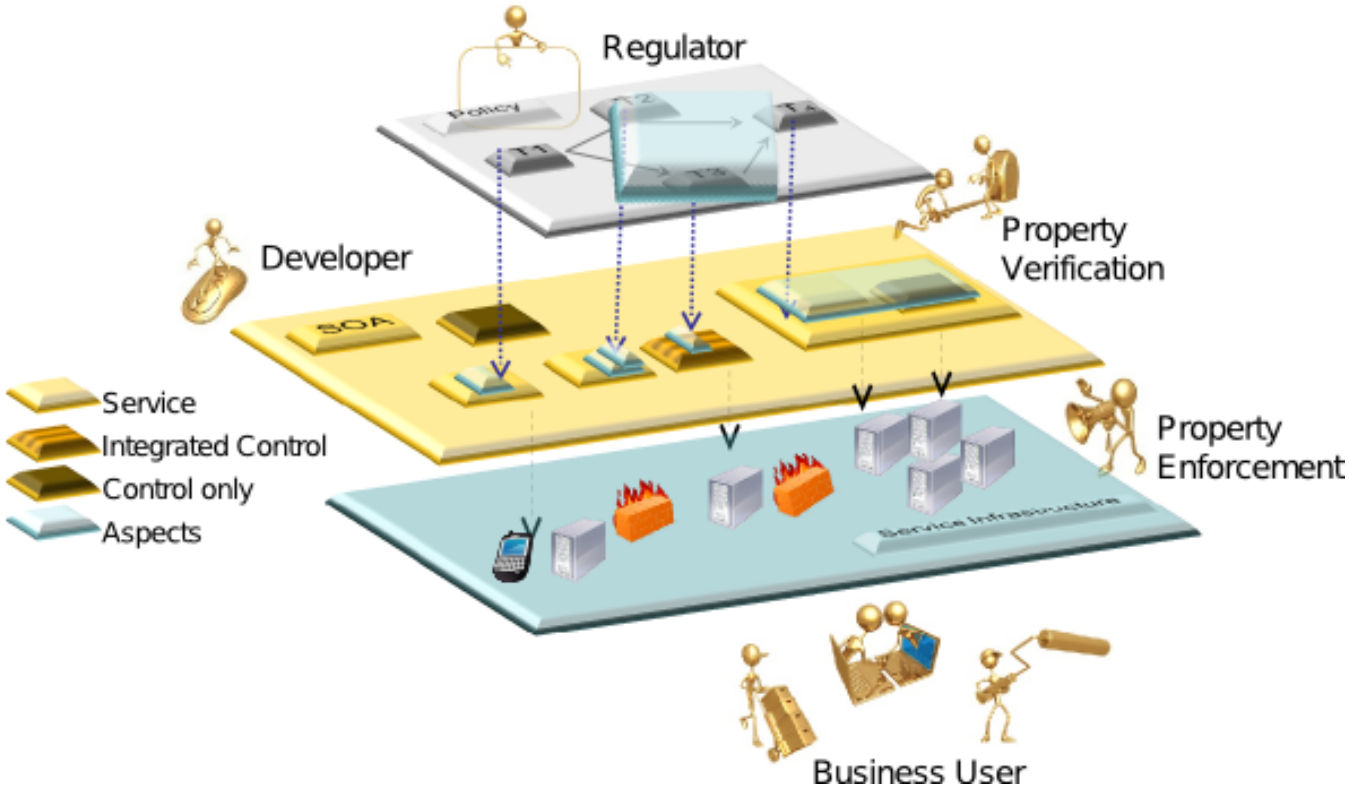
- Aspects and security
- Property-aware aspect interfaces
- Event-based aspects patterns for distribution

Aspects and security

- Security: paradigmatic crosscutting functionality
  - Formalization critical
  - Many different properties
    - High-level: authorization, authentication, confidentiality, ...
    - Low-level: information-flow, control-flow, ...
- Formal models needed for base program, aspect/aspect weaving and security properties

Ex.: aspects for secure service compositions

- Context: horizontal and vertical service compositions (choreography/orchestration and service implementation)



- Ex.: regulatory changes entail changes to both composition types (use case: SAP)

Secure service compositions: base, aspect models

- Base program
  - Collaboration model for choreography
  - π-based processes for vertical implementation
- Aspects: need to represent multiple features
  - Horizontal comp.: distribution features
  - Vertical comp.: sequential model

Secure service compositions: secure interactions

Security properties defined based on session types [Honda, Vasconcales et al.]

- Expressive model of interaction
  - Multiparty
  - Asynchronous and synchronous communication
  - Event-based interactions
  - Dynamic (multi)roles
- Global protocol for system understanding
- Projection: per-site protocols used for implementation and type-based verification
- Type safety, refinement and progress properties

Property-aware aspect interfaces

- Restrict aspects by properties on external and internal events
  - Structural conditions
  - History-based pointcuts
  - Data-flow or possibly even information flow
  - Other more expressive properties
- Generalization of existing approaches to aspects and modules
  - Flexible model of black box to (guarded) white box compositions
  - Corresponding notions of refinement?

Distributed events and patterns

- Relevant for numerous distributed applications
  Service compositions, Cloud (virtualization, map-reduce) ...
- Distributed event models are tricky
  - Complex event definitions
  - Grouping, scope and lifetime of events
  - Ordering causal relationships
  - Efficient implementation

Distributed aspects

- Many crosscutting uses of events
- Low-level definition in terms of event groups, scopes, casual relationships
- High-level abstraction: distribution, interaction patterns
- High-level properties?
  - Exclusion of race conditions in pattern compositions
  - Interactions between patterns that involve the same sites or even computations

Outline

4. The crossroads?

Initial questions revisited

- Formal AO at the center of SE problems?
  - Not yet! Close?
- Right direction?
  - Yes! More work on connection with and applications to other fields.
  - Pace of progress?

Conclusion

- **More work on connection and application**
- Important means: general models and properties

- But work on the foundations for aspects (only) is still worthwhile . . . especially to look for holy grails (e.g., "The theory of crosscutting") :)