Translucid Contracts

in

The Ptolemy Programming Language

(Expressive Specification & Modular Verification for Aspect-oriented Interfaces)




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6 Known Problems in AO Literature

How to overcome pointcut fragility? [Tourwé-Brichau- Gybels SPLAT'03, Stoerzer-Graf ICSM'05, …]	How to address quantification failure? [Sullivan et al. ESEC/FSE'05, Griswold et al. IEEE Software 2006, …]	How to make context access expressive? [Sullivan et al. ESEC/FSE'05, Griswold et al. Software 2006, …]
How to limit the number of composition-related verification tasks due to pervasive join points? [Clifton-Leavens'03, Aldrich'05, Dantas-Walker'06, …]	How to modularly verify control effects of aspects? [Zhao-Rinard FASE'03, Rinard-Salcianu-Bugrara FSE'04, …]	How to modularly verify heap effects of aspects? [Clifton-Leavens FOAL'03, Katz FOAL'04, Krishnamurthi FSE'04, …]

Fragility & Quantification

- Fragile Pointcuts: consider method “settled”

```
Fig around(Fig fe) :
call(Fig+.set*(..)) && target(fe)
...
```

Inadvertant match with regex-based pointcut

- Quantification Failure: Arbitrary events not available

```
Fig setX(int x){
  if (x == this.x) return;
  else {
    this.x = x;
  }
}
```

Abstract events often not available at the interface.

Context access

- Limited Access to Context Information
  - Limited reflective interface (e.g. "thisJoinPoint" in AJ)
  - Limited Access to Non-uniform Context Information

```
Fig around(Fig fe) :
call(Fig+.set*(..)) && target(fe)
|| call(Fig+.makeEq*(..)) && args(fe){
...
```

Encoding knowledge about base code in aspect

Pervasive Join Point Shadows

```
1 x = o1.m1(a.e1(), b.e2());
2 y = o2.m2(c.e3(), x);
```

8 Join Points

❖ For each join point shadow, all applicable aspect should be considered (whole-program analysis)

6 Known Problems in AO Literature

Hridesh Rajan and Gary T. Leavens, “Ptolemy: A Language with Quantified, Typed Events,” In proceedings of ECOOP 2008.

Available at: http://www.cs.iastate.edu/~ptolemy/
under MPL 1.1 since September 2006.

Around the same time:
<u>EJP:</u> Hoffman & Eugster`07,
<u>IIIA:</u> Steimann et al.`10

How to modularly verify <u>control effects of aspects</u>?
[Zhao-Rinard FASE’03, Rinard-Salcianu-Bugrara FSE’04]

How to modularly verify <u>heap effects of aspects</u>?
[Clifton-Leavens FOAL’03, Katz FOAL’04, Krishnamurthi FSE’04]

Ptolemy's Design

- Inspired from implicit invocation (II) approaches [Field: Reiss`90, II: Garlan-Notkin`91, Rapide: Luckham-Vera`95]

- … as well as from aspect-oriented (AO) approaches [HyperJ: Ossher & Tarr, AspectJ: Kiczales et al.`01, Caeser: Mezini & Ostermann`03, Eos: Rajan & Sullivan`03, XPI: Sullivan et al.`05, Griswold et al.`06, OM: Aldrich`05, AAI: Kiczales & Mezini`05]

Ptolemy's Design Goals

- Enable modularization of crosscutting concerns, while preserving encapsulation of object-oriented code,
- enable well-defined interfaces between object-oriented code and crosscutting code, and
- enable separate type-checking, separate compilation, and modular reasoning of both OO and crosscutting code.

First and foremost

- Main feature is event type declaration.

- Event type declaration design similar to API design.
  - What are the important abstract events in my application?
  - When should such events occur?
  - What info. must be available when such events occur?

- Once you have done it, write an event type declaration.

Type Declaration for Abstract Events

```
Fig event Changed {
  Fig fe;
}
```

Event Type Declaration

- Event type declaration is an abstraction.
- Declares context available at the concrete events.

Explicit, More Declarative Event Announcements

Subject

```
class Fig {bool isFixed;}
class Point extends Fig{
 int x, y;
 Fig setX(int x){
  announce Changed(this){
   this.x = x; return this;
  }
 }
}
```

Event Announcement

- Explicit, more declarative, typed event announcement.

Advising Events

- No special type of "aspect" modules
  - Unified model from Eos [Rajan and Sullivan 2005]

Observer(Handler)

```
class Enforce {
 @Register
 Enforce(){}



}
```

Registration

Quantification Using Binding Decls.

- Binding declarations
  - Separate "what" from "when" [Eos 2003]

Observer (Handler)

```
class Enforce {
 @Register
 Enforce(){}

 Fig enforce(Changed next){




 }
 when Changed do enforce;
}
```

Quantification

Controlling Overriding

- Use ***invoke*** to run the continuation of an event
  - Allows overriding similar to AspectJ

Observer(Handler)

```
class Enforce {
 @Register
 Enforce(){}

 Fig enforce(Changed next){
   if(!next.fe.isFixed)
    return invoke(next);
   else
    return next.fe;
 }
 when Changed do enforce;
}
```

Running continuation

Ptolemy Example: All Together

Subject

```
class Fig {bool isFixed;}
class Point extends Fig{
 int x, y;
 Fig setX(int x){
  announce Changed(this){
   this.x = x;return this;
  }
 }
}
```

Event Type

```
Fig event Changed {
 Fig fe;










}
```

Observer(Handler)

```
class Enforce {
 @Register enforce(){}
 Fig enforce(Changed next){
  if(!next.fe.isFixed)
   return invoke(next)
  else
   return next.fe;
 }
 when Changed do enforce;
}
```

Event Announcement

Event Declaration

Quantification

- Skip the execution of *setX()* when *isFixed* is true.
- Event-driven-programming:
  - Subject Point announces event Changed when *setX()* is called.
  - Event handler enforce registers for Changed and runs upon its announcement.
  - Handler enforce implements the example requirement
- … also supports mixin-like inter-type declarations [Bracha & Cook]

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How to modularly verify control effects of aspects?
[Zhao-Rinard FASE'03, Rinard-Salcianu-Bugrara FSE'04]

This Talk

How to modularly verify heap effects of aspects?
[Clifton-Leavens FOAL'03, Katz FOAL'04, Krishnamurthi FSE'04]

Since these definitions differ ...

BASIC DEFINITIONS

When is separation of crosscutting concerns accomplished?

- Scattered and tangled concerns are textually separated,

+

- one can modularly verify module-level properties of separated concerns.

When is a verification task "modular"?

- If it can be carried out using:
  - the code in question

$$+$$

  - specifications of static types mentioned in code.

Understanding Control Effects

```
class Enforce {
 …
 Fig enforce(Changed next){
  if(!next.fe.isFixed)
   return invoke(next)
  else
   return next.fe;
 }
 when Changed do enforce;
}
```

```
class Logging{
 …
 Fig log(Changed next){
  if(!next.fe.isFixed)
   return invoke(next);
  else {
   Log.log(next.fe); return next.fe;
 }}
 when Changed do log;
}
```

- Logging & Enforce advise the same set of events, Changed
- Control effects of both should be understood when reasoning about the base code which announces Changed

Can Specifications help?

```
Fig event Changed {
 Fig fe;
 requires fe != null
 ensures fe != null
}
```

```
class Enforce {
 …
 Fig enforce(Changed next){
  if(!next.fe.isFixed)
   return invoke(next)
  else
   return next.fe;
  }
```

```
class Logging{
 …
 Fig log(Changed next){
  if(!next.fe.isFixed)
   return invoke(next);
  else {
   Log.log(next.fe); return next.fe;
  }}
 when Changed do log;
}
```

Blackbox Can't Specify Control

```
Fig event Changed {
 Fig fe;
 requires fe != null








 ensures fe != null
}
```

```
class Enforce {
 …
 Fig enforce(Changed next){
  if(!next.fe.isFixed)
   return invoke(next)
  else
   return next.fe;
```

```
class Logging{
 …
 Fig log(Changed next){
  if(!next.fe.isFixed)
   return invoke(next);
  else {
   Log.log(next.fe); return next.fe;
  }}
 when Changed do log;
}
```

- Blackbox isn't able to specify properties like "advice must proceed to the original join point".
  - If invoke goes missing, then execution of Logging is skipped.
    - Ptolemy's invoke = AspectJ's proceed

Blackbox Can't Specify Composition

```
class Enforce {
 …
 Fig enforce(Changed next){
  if(!next.fe.isFixed)
   return invoke(next)
  else
   return next.fe;
 }
 when Changed do enforce;
}
```

```
class Logging{
 …
 Fig log(Changed next){
  if(!next.fe.isFixed)
   return invoke(next);
  else {
   Log.log(next.fe); return next.fe;
 }}
 when Changed do log;
}
```

- Different orders of composition may results in different control flow if invoke is missing
  - Logging runs first, Enforce is <u>executed</u>
  - Enforce runs first, Logging is <u>skipped</u>

Translucid Contracts (TCs)

- TCs enable specification of control effects
- Greybox-based specification [Büchi and Weck`99]
  - Hides some implementation details
  - Reveals some others
- Limits the behavior & structure of aspects applied to AO interfaces

Translucid Contracts Example

```
Fig event Changed {
 Fig fe;
 requires fe != null
 assumes{
  if(!fe.isFixed)
   return invoke(next)
  else
   establishes fe==old(fe)
 }
 ensures  fe != null
}
```

Translucid Contract

- Limits the behavior of the handler
  - **requires/ensures** labels pre/postconditions
- Greybox limits the handler's code
  - **assumes** block with program/spec. exprs

Assumes Block

```
Fig event Changed {
 Fig fe;
 requires fe != null
 assumes{
  if(!fe.isFixed)
   return invoke(next)
  else
   establishes fe==old(fe)
 }
 ensures fe != null
}
```

- A mixture of
  - Specification exprs
    - Hide implementation details
  - Program exprs
    - Reveal implementation details

TCs Can Specify Control

```
Fig event Changed {
 Fig fe;
 requires fe != null
 assumes{
  if(!fe.isFixed)
   return invoke(next)
  else
   establishes fe==old(fe)
 }
 ensures fe != null
}
```

```
class Enforce {
 …
 Fig enforce(Changed next){
  if(!next.fe.isFixed)
   return invoke(next)
  else
   return next.fe;
 }
 when Changed do enforce;
}
```

1. TC specifies control effects independent of the implementation of the handlers Enforce, Logging, etc.
2. invoke(next) in TC assures invoke(next) in enforce cannot go missing.
   - Proceeding to the original join point is thus guaranteed.
3. Different orders of composition of handlers doesn't result in different control flow.

Modular Verification of Ptolemy Programs

1. Verifying that a handler refines the contract of the event it handles.
   - Verified modularly

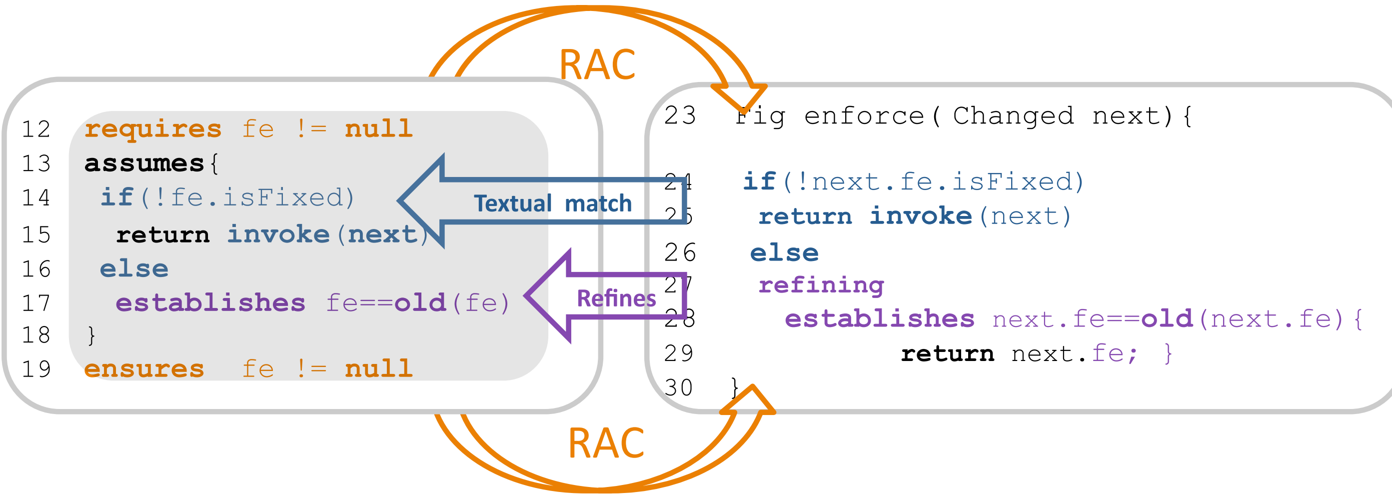
2. Verifying code containing announce/invoke exprs.
   - which cause unknown set of handlers to run.
     - Verified modularly

Translucid contracts enable modular verification of control effects.

Handler Refinement

- A handler structurally matches the assumes block of the TC of the event it handles.
  - Structural refinement
  - Statically, during type-checking
- A handler respects pre/postconditions of the requires/ensures predicate in TC.
  - Dynamically, using runtime assertion checks

Handler Refinement



- Structural refinement:
  - A program expr. is refined by a textually matching prog. expr.
  - A specification expr. is refined by a refining expr. with the same spec.
  - Structural refinement is done statically at type-checking phase.
- TC's Pre-/postconditions are enforced using runtime assertion checks (RACs)

Verification of Announce & Invoke

- Announce & Invoke cause,
  unknown set of handlers to run.

- Translucid contracts,
  provide a sound spec. of the behavior for
  an arbitrary number of handlers

- Translation function, Tr, computes the specification.

Verification of Announce, Subject Code

- Apply Tr to the code containing announce:
  - Tr replaces announce with a spec representing situations when there are:
    - No More handlers to run
      - Event body is executed
    - More handler to run
      - Next handler is executed.
        Translation of the TC is the spec of the running handler

Example of Verification of Announce, Subject Code

```
Fig setX(int x){
 announce Changed(this){
  this.x = x; return thi
 }
}
```

Apply
Tr

```
Fig setX(int x){
 requires fe != null
  either{
   this;
   this.x = x; return this;}

  or{
   Fig fe = this;
   Tr(
    if(!fe.isFixed)
     return invoke(next)
    else
     establishes fe==old(fe)
   )}
 ensures fe != null
}
```

- Replace announce by the spec. computed by Tr function.
- either branch: no more handlers to run: event body + parameters
- Or branch: more handlers to run: apply Tr to TC's assumes block

Verification of Announce & Invoke, Similarities & Differences

- Apply Tr to the code containing announce/invoke:
  - Tr replaces announce/invoke with a spec representing situation where there are:
    - No More handler to run
      - Announce: Event body is executed and is accessible.
      - Invoke: Event body is executed but not accessible.
        TC's requires/ensures represent the event body.
    - More handlers to run
      - Announce/invoke: Next handler is executed.
        Translation of the TC is the spec of the running handler

Runtime Assertion Checking (RAC)

- RACs are used to enforce:
  - Requires/ensures predicates of the TC , at:
    - beginning/end of each refining handler.
    - before/after invoke exprs.
    - before/after announce exprs.
    - beginning/end of event body.
  - Spec. of the refining exprs, at:
    - beginning/end the refining expr. block

Expressiveness of TCs

- All categories of Rinard's control interference & beyond are expressible using TCs

- Rinard's control interference categories are concerned about:
  - Number of invoke (proceed) exprs in the handler (advice)
  - details in paper.

Related Ideas

- Contracts for Aspects
  - XPI [Sullivan et al.`09], Cona[Skotiniotis & Lorenz`04], Pipa [Zhao & Rinard`03]
    - XPI's contracts informal, all blackbox contracts
- Modular reasoning for Aspects
  - [Krishnamurthi, Fishler, Greenburg`04]
    - Blackbox contracts, global pre-reasoning step
  - [Khatchadourian-Dovland-Soundarajan`08]
    - Blackbox contracts, additional pre-reasoning step to generate traces.
- Effective Advice [Oliveira et al.`10]
  - No quantification

Conclusion & Future Work

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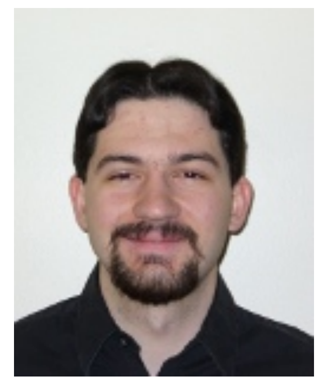
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