Translating Java bytecode to BoogiePL

Master project - Final presentation

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Outline

Recap

What has changed?

Formalization of the translation

Boogie modifications

Conclusion

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- Providing a translation from bytecode to BoogiePL
  - Including exceptions
- Formalizing the translation in Coq
  - Basis for a soundness proof
- Extending Boogie to support exceptions

Translating an example

- Java source

```
public class Account {
    private int balance;
    public void deposit(int amount) { balance = balance + amount; }
}
```

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public class Account {
    private int balance;
    public void deposit(**int** amount) { balance = balance + amount; }
}

- JVM bytecode

```
public void deposit(int);
0:   aload_0
1:   aload_0
2:   getfield   #2; //Field balance:I
5:   iload_1
6:   iadd
7:   putfield   #2; //Field balance:I
10:  return
```

Translating an example (cont'd)

```
implementation Account.deposit(this: ref, param1: int) {
 init:
   assume this ≠ null ∧ typ(rval(this)) = Account;
   reg0r := this;    // argument to register transfer
   reg1i := param1;
   goto block_0;
 block_0:
   stack0r := reg0r; // aload_0
   stack1r := reg0r; // aload_0
   stack1i := toint(get(heap, fieldLoc(stack1r, Account.balance)));
   stack2i := reg1i; // iload_1
   stack1i := stack1i + stack2i; // iadd
   heap := update(heap, fieldLoc(stack0r, Account.balance), ival(stack1i));
   return;
}
```

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Generic stack manipulation instructions (e.g. `dup`, `swap`) relied on type of stack elements.

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- Unnecessary complexity

  // dup
  stack$(h+1)[\mathit{stackType}(h)]$:= stack$(h)[\mathit{stackType}(h)]$;

- Solution: just perform operation on all types

  // dup
  stack$(h+1)$i := stack(h)i; *// primitive*
  stack$(h+1)$r := stack(h)r; *// reference*

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function fieldLoc(ref, name) returns (Location);
function arrayLoc(ref, int) returns (Location);
```

- Data model closer to Java (uses values now, not objects)

```
function update(Store, Location, Value) returns (Store);
function add(Store, Allocation) returns (Store);
function get(Store, Location) returns (Value);
function alive(Value, Store) returns (bool);
function new(Store, Allocation) returns (Value);
```

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assume $(\forall$ v: Value $\circ$ alive(v, pre_heap) $\Rightarrow$ alive(v, heap));

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  assume ($\forall$ v: Value $\circ$ alive(v, pre_heap) $\Rightarrow$ alive(v, heap));

- Locations not in callee **modifies** remain unchanged

  assume ($\forall$ h: Store, l: Location, v:Value $\circ$ l $\neq$ Account.balance $\Rightarrow$
  get(heap, l) = get(pre_heap, l));

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- Static fields: Introduce *type object*

function typeObject(t: **name**) **returns** (**ref**);
axiom ($\forall$ t: **name** $\circ$ typeObject(t) $\neq$ **null**);

// getstatic int C.f
stack($h+1$)i := toint(get(heap, fieldLoc(typeObject(C), C.f)));

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stack(h + 1)i := toint(get(heap, fieldLoc(typeObject(C), C.f)));
```

- Treat static methods same as instance, just omit implicit **this** parameter

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- Includes formalization of BoogiePL language
- Depends on bytecode formalization library *Bicolano*
- Type-checkable $\Rightarrow$ guarantees syntactically correct BoogiePL
- Basis for a soundness proof

Layout of development

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- `BoogiePL.v`: Formalization of BoogiePL language
  - Basically a description of the grammar
- `BoogieUtils.v`: Helper library for building expressions
  - Grammar makes it hard to create expressions directly
- `Translation.v`: Translation of bytecode methods to BoogiePL programs

Example: Translating swap

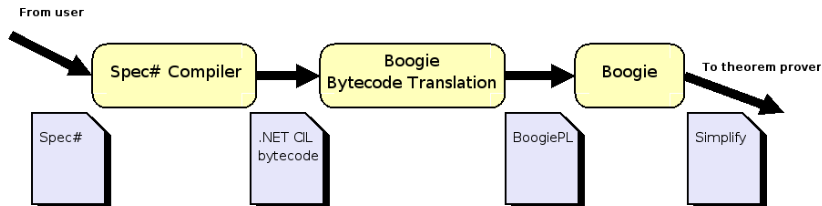
```
Definition TrInstruction (bm: BytecodeMethod) (pc: PC)
    (cur: Boogie.Block) : ( list Boogie.Block * Boogie.Block) :=

match BYTECODEMETHOD.instructionAt bm pc with
 ...
| Swap ⇒ match cur with
  | (blockid ,cmds,toc) ⇒ (blockid, cmds++(
    Assign (swapvar Ref) (BPL.IdentExpr (stvar (h−1) Ref))::
    Assign (swapvar Int) (BPL.IdentExpr (stvar (h−1) Int))::
    Assign (stvar (h−1) Ref) (BPL.IdentExpr (stvar h Ref))::
    Assign (stvar (h−1) Int) (BPL.IdentExpr (stvar h Int ))::
    Assign (stvar h Ref) (BPL.IdentExpr (swapvar Ref))::
    Assign (stvar h Int) (BPL.IdentExpr (swapvar Int ))::
     nil
   ))
  end
 ...
```

Example: Boogie declarations

```
(* Declarations *)
Inductive Declaration : Set :=
| TypeDecl (ids: list Identifier)
| ConstantDecl (idtypes: list (Identifier * BPLType))
| FunctionDecl (ids: list Identifier)
    (params: list (option Identifier * BPLType))
| AxiomDecl (e: Expression)
| VariableDecl (idtypes: list (Identifier * BPLType))
| ProcedureDecl (id: Identifier) (params: list (Identifier * BPLType))
    (returnType: option BPLType) (specs: list Specification)
| ImplementationDecl (id: Identifier)
    (params: list (Identifier * BPLType))
    (returnType: option BPLType) (body: Body).
```

Boogie modifications: Overview



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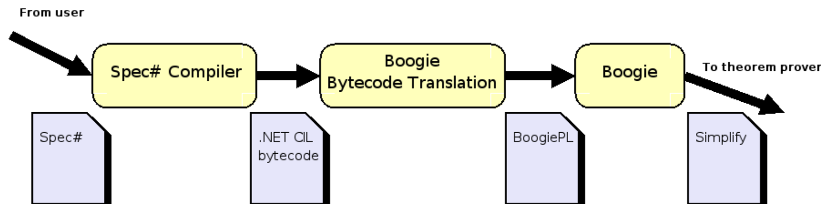

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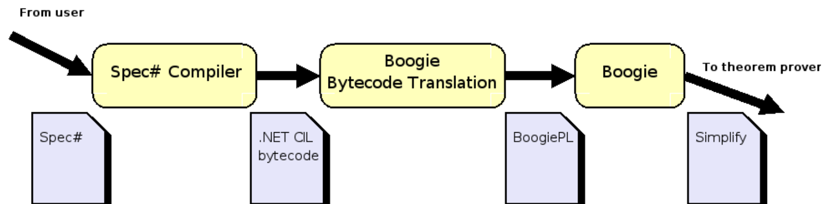

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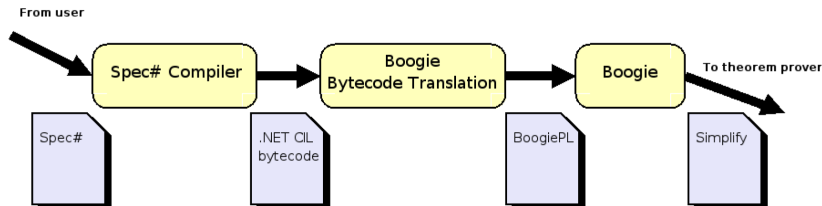

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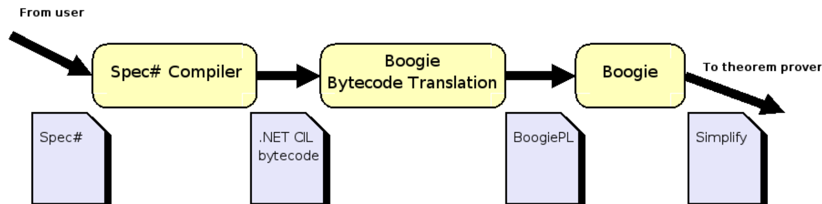

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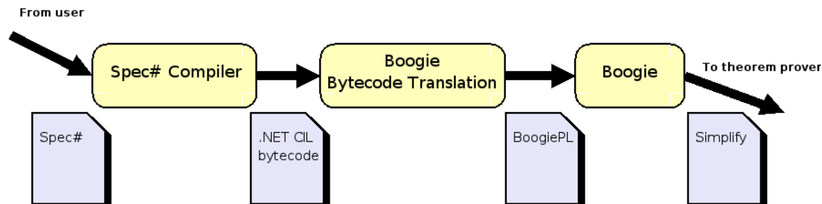

- Boogie does not translate exceptions
- Modifications to incorporate our methdology
  - Code in `catch` blocks
  - Exceptional method termination
  - Throwing exceptions
- New commandline switch `/experimentalExceptions`

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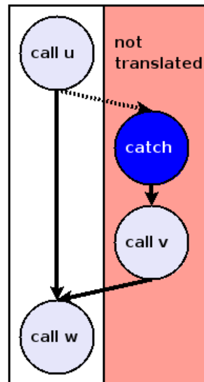
- `catch` handlers are exceptional successors of other nodes
- But: translation only considers normal successors

```
try {
    u();
} catch (Exception){
    v();
}
w();
```



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- Exceptional successors are no longer ignored
- `catch` (InsufficientFundsException) translates to

  block_[*catch*]:
  havoc stack0o;
  assume cast(Heap[stack0o, allocated], **bool**) = true
  $\wedge$ stack0o $\neq$ **null**
  $\wedge$ typeof(stack0o) <: InsufficientFundsException ;
  // branch to handler code
  goto block_[*handler*];

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```
Desugar[[result := call C.m(x,y)]] := {
    var call@formal@0: int, call@formal@1: int;
    call@formal@0 := x;
    call@formal@1 := y;

    assert Precondition(C.m, prestate);
    havoc Heap, result;
    assume Postcondition(C.m, prestate, poststate);
}
```

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Method invocation: After

Desugar **call** statement “early”

- Split desugaring over multiple blocks
- Successor blocks for normal and exceptional execution
  - Spec# doesn’t have exceptional postcondtions yet
  - Exceptional case not really useful right now
  - `throws` clause not serialized ($\Rightarrow$ next release)

Method invocation: After (cont'd)

```
block_2042:
    call@formal@0 := x;
    call@formal@1 := y;
    call@old@Heap := Heap;
    assert Precondition(C.m, prestate);
    havoc Heap, result;
    goto block_2042_N, block_2042_X;

block_2042_N: // normal termination
    assume Postcondition(C.m, prestate, poststate);
    ...          // normal continuation

block_2042_X: // exceptional termination
    assume ExcpPostcondition(C.m, prestate, poststate);
    goto block_[handler];
```

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- Throwing an exception generates the following code:

  assert stack(h)r $\neq$ **null**;
  assume false; *// !*
  return;

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- After an **assume** false; Boogie will “verify” anything, postcondition violations are ignored.

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Case distinction:

- Exception is caught (fully or partially):

  assert stack(h)r $\neq$ **null**;
  goto block_[*handler*];

- No handler: old behavior (no exceptional postconditions yet)

  assert stack(h)r $\neq$ **null**;
  assume false;
  return;

Demo

```
public static void transfer (Account! src, Account! dest, int amount)
     requires amount > 0;
    throws TransferFailedException
{
    try {
        src.withdraw(amount);
    } catch ( InsufficientFundsException e) {
        throw new TransferFailedException();
    }
    dest.deposit(amount);
}
```

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- Formalization of the translation for the Coq theorem prover
  - Basis for a soundness proof
- Boogie modifications for our approach of dealing with exceptions

Future work

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- Exception methodology for Spec# (exceptional postconditions)

Questions

? ? ?

Sushi apéro

Sushi apéro @ RZ F11, 15.00
Feel free to join!

Frame conditions

```
// requires amount > 0;
// modifies this.balance;
// ensures balance + amount == old(balance);
// when InsufficientFundsException ensures balance == old(balance);
public void withdraw(int amount) throws InsufficientFundsException {
    ...
}

public static void transfer(Account src, Account dest, int amount) {
    try {
        src.withdraw(amount);
    } catch (InsufficientFundsException e) {
        ...
    }
    ...
}
```

Frame conditions (cont'd)

```
  assume (forall v: Value ∘ alive(v, pre_heap) ⇒ alive(v, heap));
  assume (forall h: Store, l: Location, v:Value ∘
    l ≠ fieldLoc(arg0r, Account.balance)
    ⇒ get(heap, l) = get(pre_heap, l));
  goto block_2_N, block_2_InsufficientFundsException ;
block_2_N:
  assume stack1i > 0 ⇒ // normal postcondition
        toint(get(heap, fieldLoc(arg0r, Account.balance))) + stack1i
        = toint(get(pre_heap, fieldLoc(arg0r, Account.balance)));
   ...
 block_2_InsufficientFundsException :
  havoc stack0r; // exceptional postcondition
  assume alive(rval(stack0r), heap);
  assume typ(rval(stack0r)) <: InsufficientFundsException ;
  assume true ⇒ get(pre_heap, fieldLoc(arg0r, Account.balance)) =
                                   get(heap, fieldLoc(arg0r, Account.balance));
   ...
```

Normal and exceptional postconditions

Normal and exceptional postconditions:

```
// ensures balance + amount == old(balance);
// when InsufficientFundsException ensures balance == old(balance);
public void withdraw(int amount) { ...}

post:
    // old(this.balance) == this.balance + param1
    assert toint(get(old_heap, fieldLoc(this, Account.balance))) ==
           toint(get(heap, fieldLoc(this, Account.balance))) + param1;
    return;

 post_X_InsufficientFundsException :
    // old(this.balance) == this.balance
    assert toint(get(heap, fieldLoc(this, Account.balance))) ==
           toint(get(old_heap, fieldLoc(this, Account.balance)));
    return;
}
```