Contracts as a support to static analysis of open systems

Work in progress

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Static Analysis

- Family of techniques used to analyse program behaviors and deduce program properties
- The precision of the result depends on the precision of starting hypotheses. For example:
  - Precision of the abstract domains
  - Restriction of the input domains

```
void m1 (int a) {
  int v;
  if (a > 100)
    v = m2 (a);
  else
    v = m2(a%2);
  m2(a);
  ...
}
```

```
int m2 (int a) {
  if (a == 1)
    return 0;
  if (a == 0)
    return 2;
  return m3 (a);
}
```

Open Object-Oriented world

Object-Oriented

- Virtual invocations ➠ not possible to decide which code will be executed
- Except in particular cases
  - Exact types computation
  - Extra-knowledge: call graph, class hierarchy (context-sensitive analysis, complete graph unfolding)

Open

- New sub-classes
- New calling contexts for old methods ➠ may change the hypotheses under which the analysis has been done

Object-Oriented + Open ➠ Highly dynamic

Proposition

Idea

Compositional analysis of methods based on the notion of

contract

Major interests:

- To analyse a method when the called methods are not available

  ➠ dynamic loading

- To use contracts when loading a new method:
  - New code must respect required contracts

    ➠ already established properties still hold
  - New code uses contracts of old code

    ➠ No need to re-analyse old code in new context

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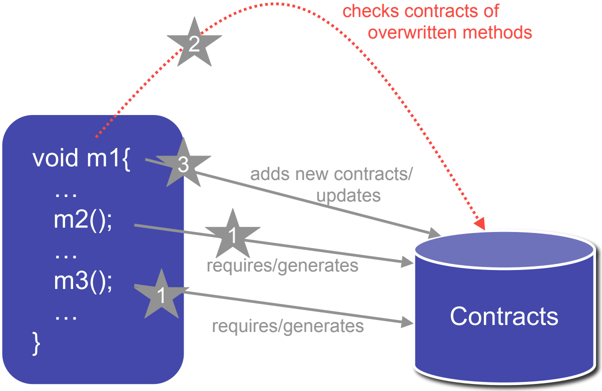
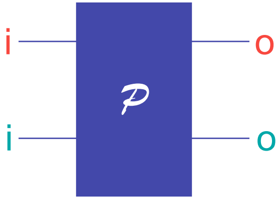
Principle


checks contracts of
overwritten methods
2
void m1{
3
adds new contracts/
updates
…
m2();
1
…
requires/generates
m3();
1
…
requires/generates
}
Contracts

Information flow



Goal

- To detect ”illegal” flows between data
- To prove non-interference

Usual solutions

- Well typed program ➠ secure
- Powerfull but problems for open systems, extensible, dynamical updates, multi-applications sharing code, different security policies applied to shared code, . . .

Proposition: Dependency calculus

- Computes the ”links” between data accessed by a method
- Results can be exploited *a posteriori*
- Contracts make the analysis compositional

Contracts for dependency calculus

What? The method signature is enriched with dependency informations

Guaranty: The method does not produce more dependencies than announced in its contract **if** used methods respects their own contracts

How? The method contract is computed (or verified) by abstract interpretation of the method code, contracts of called methods are used in the abstract semantics rule

$$\frac{(\mathcal{V}, u_n :: \cdots :: u_0 :: s, DPG) \quad \mathcal{C}_m}{(\mathcal{V}, ret :: s, DPG \oplus \mathcal{C}_m)} \; \texttt{invoke m}$$

- No need to re-analize called code
- No need to know the complete class hierarchy

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Contracts management

Inheritance

- Contracts of new methods must be *compatible* with the contracts of overwritten methods and interface contracts (Lattice structure)

➠ When analyzing a call to a method *m* of an object *o*, the static type of *o* can be used to find the contract of *m*

Missing contracts in the base

- Given by the user:
  - For native methodes ➠ trusted base
  - For conceptions reasons ➠ verified when the code arrives
- Not available
  - Set to the greatest element of the lattice ➠ respected by any forthcoming contract
  - We are not able to infer the missing contracts yet

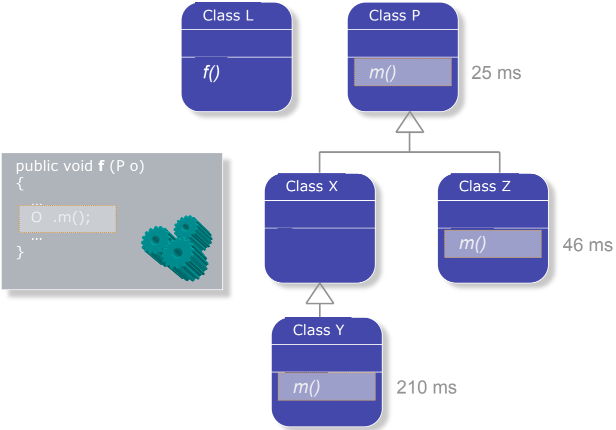
WCET in a few words

Prediction of the worst case execution time of a program

- Intra-method analysis
  - Estimation of execution time of basic blocks
  - Bound of the number of iterations
  - ...
- Inter-method analysis: end-to-end timing behavior
  - Usually: for each method invocation, the algorithm is called recursively. The WCET calculus is propagated from the leaves of the call graph to the root
  - For polymorphic calls

- RT contracts: for each method $\text{WCET}(m) \leq \textit{deadline}(m)$

WCET in a few words



WCET in a few words

Prediction of the worst case execution time of a program

- Intra-method analysis
  - estimation of single execution time
  - bound of the number of iterations
  - ...
- Inter-method analysis: end-to-end timing behavior
  - In closed world: for each method invocation, the algorithm is called recursively. The WCET calculus is propagated from the leaves of the call graph to the root
  - For polymorphic calls

$$\text{WCET}(C.m) = \underset{C' \sqsubseteq C}{Max}\, W(C'.m)$$

- RT contracts: for each method $\text{WCET}(m) \leq deadline(m)$

Example

```
void A(){
    if (exp)
        statement;
    else
        B();
}
```

We are able to infer contracts for forthcoming methods !

$$\begin{aligned} W(\texttt{A}) &= W(\texttt{if}) + W(\texttt{exp}) + Max(W(\texttt{statement}), \mathrm{WCET}(\texttt{B})) \\ deadline(\texttt{A}) &\geq W(\texttt{A}) \\ &\geq W(\texttt{if}) + W(\texttt{exp}) + Max(W(\texttt{statement}), \mathrm{WCET}(\texttt{B})) \end{aligned}$$

- If $deadline(\texttt{A}) < W(\texttt{if}) + W(\texttt{exp}) + W(\texttt{statement})$ then A is not valid
- Otherwise the contract $Cst \geq \mathrm{WCET}(\texttt{B})$ where $Cst = deadline(\texttt{A}) - W(\texttt{if}) - W(\texttt{exp})$ is added to the contract repository

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Contract management

Contract repository

- Already computed WCET of methods
- Deadlines of methods
- Contracts for forthcoming methods

A new method $C.m$

- Must verify $W(C.m) \leq Min_{C \sqsubseteq C'} \text{WCET}(C'.m)$
- Must verify all pending contracts that imply $C.m$
  - No need to solve equation ➠ only replace the unknown by the value of $W(C.m)$ and check the result
  - When contracts have several unknowns ➠ first in is right

Reduction of the repository

- Contracts for the same method can be reduced keeping the *Min* of deadlines

Contract lookup for $C.m$

Check contracts containing WCET($C.m$) as unknown

- If a contract is not respected, the method is rejected
- If a contract as no more unknown, it is removed
- Contract with remaining unknown are removed from the contract list of $C.m$

Check contracts of super-classes

1. Let B be the direct super-class of C
2. If B does not contain a definition of m, goto 1 with $B = C''$ if C'' is the direct super-class of B
3. If B contains a definition of m, then
   - If $W(B.m)$ is known, check that $W(B.m) \geq W(C.m)$ and stop
   - Else check that $W(C.m)$ respects the pending contracts that refer to WCET($X.m$), goto 1 with $B = C''$ if C'' is the direct super-class of B

Conclusion & Perspectives

Conclusion

- Two applications
- Implemented on small embedded systems (Java for IF and CAMILLE for WCET)

Perspectives

- Formalize a general framework
- Cases when contracts of missing code can be inferred