Static Execution Time Analysis

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Overview

- Area of interest
- Current state
- Work in progress
- What to do next

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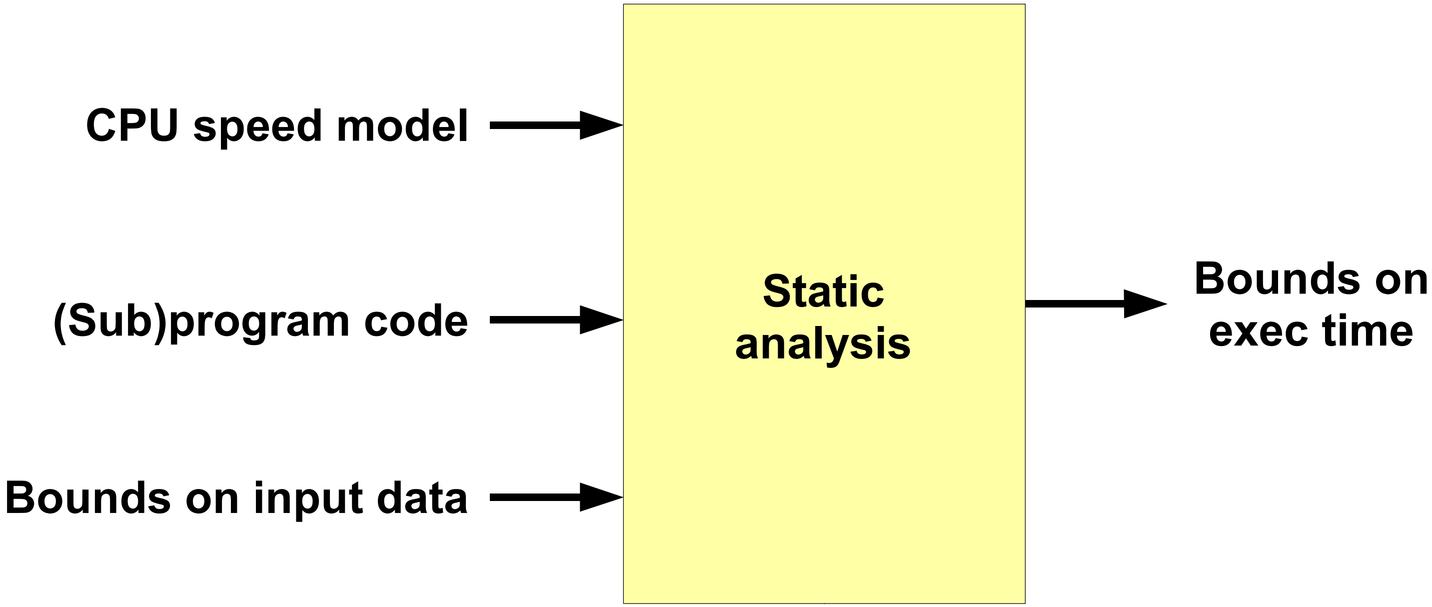
Area of interest

- *Static analysis of programs for*
  - Bounds on execution time and memory space
  - other properties that depend on:
    - the possible execution paths
    - the time/space/energy usage along the execution path
    - the sequence of actions on the execution path (~ protocols)
- *Applications*
  - analysis of executable (binary) programs
  - for embedded real-time systems
  - for verification (meets time and space limits)
  - for understanding (time and space per program part)

Static execution-time analysis



Problem is unsolvable in general <= Halting Problem.
- need restrictions on program structure
- may get pessimistic (safe but inaccurate) results

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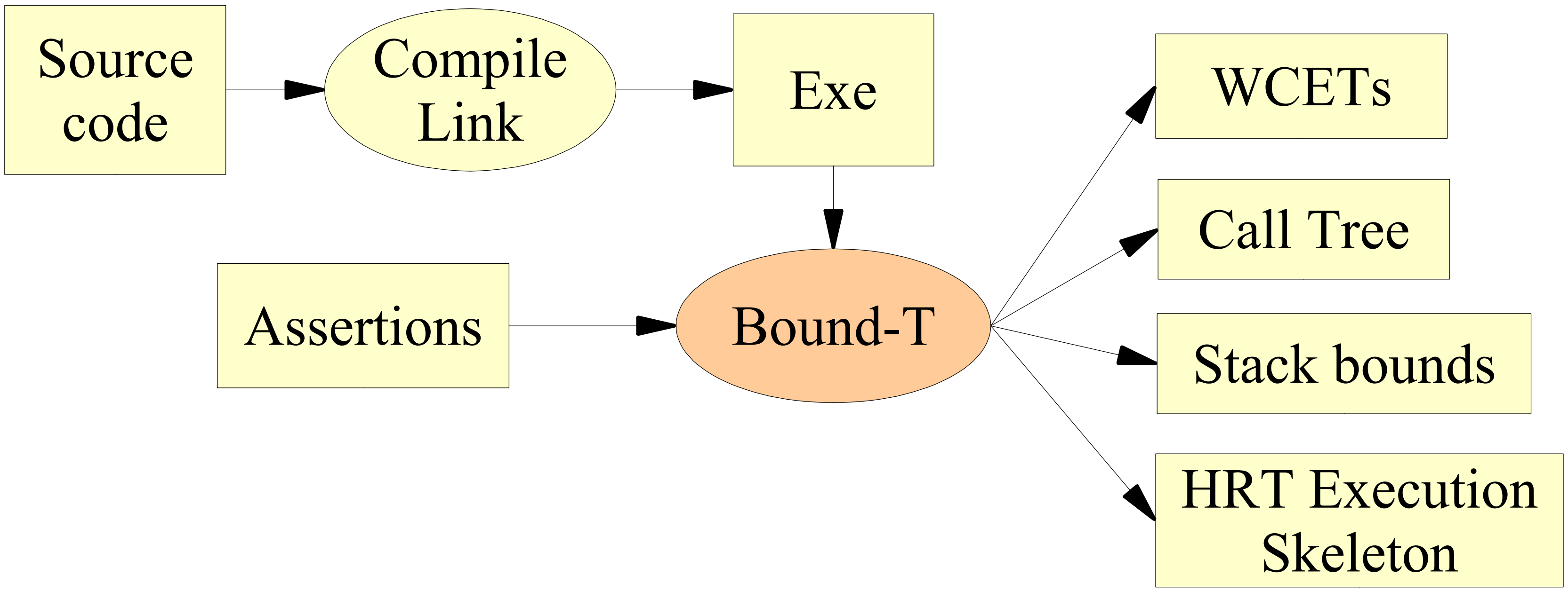
Current state = the Bound-T tool

- *Analyses worst-case execution time and stack usage*
  - for deterministic processors (no cache, linear pipeline)
    - SPARC V7 (ERC32), ADSP 21020, Intel 8051, ARM7 (proto)
  - from compiled, linked binary (no source-code analysis)
- *Implementation*
  - manually written (Ada 95)
  - modular: target-specific part + generic part
- *Generic techniques*
  - program model = flow-graphs + call-graph + assertions
  - loop counters modelled by Presburger arithmetic (Omega tool)
  - worst-case execution path from ILP (lp_solve tool)
  - assertion language using syntactic structure of program

Bound-T flow



Source code
Compile Link
Exe
Assertions
Bound-T
WCETs
Call Tree
Stack bounds
HRT Execution Skeleton

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Work in progress

- *Increasing power of arithmetic analysis*
  - Constant propagation to simplify program model
  - slicing along dependencies to simplify program model
  - optimized translation to Presburger formulae
- *Increasing power of flow analysis*
  - Less constrained loop structures (DJ method)
- *Better analysis of dynamic addresses*
  - case/switch statements, jump tables
  - array accesses, pointers to data or code
- *More powerful assertions*
  - context-dependent (call-path dependent) assertions
- *Porting to more target processors*

EU research cooperation

- *ARTIST 2 Network of Excellence*
  - proposal for EU 6th Framework Program
  - cluster: "Compilers and Timing Analysis" led by R. Wilhelm
  - participants: most EU WCET research groups
    - Saarbrücken, AbsInt, Mälardalen, TU Wien, IRISA, York, SSF, ...
  - aims defined by "integration" purpose of NoE:
    - define common modular structure of WCET tools
    - interoperation of modules from various sources
    - adapt existing academic & commercial tools to conform
  - preparation for a larger FP6 WCET proposal in mid-2004
- *ForTIA = Formal Techniques Industry Association*
  - Mainly specification & verification tools, little analysis

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What to do next in R & D

- *Feasible paths*
  - theory? representation? analysis? presentation? ...
- *Loops*
  - nested loop dependencies, eg. triangular loops
  - inter-loop dependencies
  - non-counting loops: shifting loops, binary search, ...
- *Dynamic processor architectures*
  - caches, parallel units, multiple issue, ...
- *Generative implementation of target-specific analysis modules*
  - languages to describe target processors
  - trade-off: language power <=> implementation complexity

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Example of feasible path problem (real case!)

```
procedure A is
begin
    for n in 1 .. 200 loop
        B (action(n), ok);
        exit when ok;
    end loop;
end A;
```

```
procedure B
    (act : in action_t; ok : out boolean) is
begin
    Quick_Try (act, ok);
    if ok then
        Long_Comp (act);
    end if;
end B;
```

- *Expected WCET(A, B) ~ 20 ms*
- *Syntactic paths (A, B) => Long_Comp 200 times => 4 seconds !*
- *Feasible paths (A, B) => Long_Comp once => 20 ms.*

This one could be solved by different design

```
procedure A is
begin
    for n in 1 .. 200 loop
        Quick_Try (action(n), ok);
        if ok then
            Long_Comp (action(n));
            exit;
        end if;
    end loop;
end A;
```

- *Syntactic paths (A, B) = Feasible paths (A, B)*
  => Long_Comp once => 20 ms.
- *Perhaps "inlining" during analysis would see this, too.*

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Research problems in feasible paths analysis

- *Formal representation*
  - ? similar to flow graphs, or very different (other “aspects”)
  - ? enumerative, linguistic, algebraic, automata, ...
- *Analysis*
  - ? how: discover variable relationships, condition dependencies, ...
  - ? what: find the important path constraints, ignore trivial ones
- *Generality and usefulness*
  - ? same or different path representation & analysis for
    - time analysis
    - memory analysis
    - points-to analysis
    - functional correctness & proof
    - etc.

The End

or the beginning?