Predicated Worst-Case Execution-Time (WCET) Analysis

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Roadmap

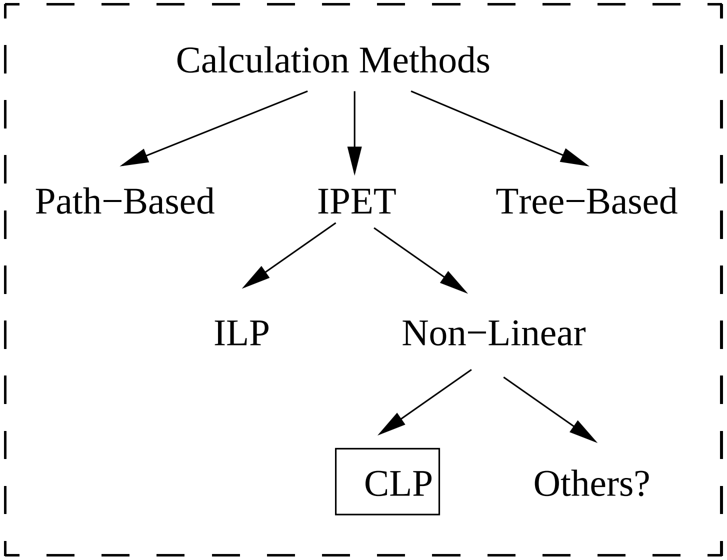
- Background
- Motivation
- Predicated WCET Analysis
- Results
- Conclusions

Background

- Generalities
  - Schedulability analysis needs WCET
    - Also optimization
  - *WCET of a task is the maximum execution time that a task can ever exhibit*
  - Goals: safety + tightness
- Types of analysis
  - Static analysis (SA)
    - flow analysis, hardware modeling, calculation
  - Dynamic analysis (end-to-end)
    - Random, GAs, best-effort, engineering wisdom
  - Measurement-based (MB)
    - flow analysis, measurements, calculation

Background: IPET

- General procedure
  - Partition into segments
  - Find execution times of segments
  - Calculate: path-based, tree-based, IPET (Implicit Path-Enumeration Technique)



Background: ILP Issue

- IPET widely used
  - Powerful constraint modeling
  - Efficient ILP solvers
  - $f = x_1 \times c_1 + x_2 \times c_2 + ... + x_n \times c_n$ (n segments) + a set of constraints
- Issue with complex hardware
  - Variable execution times
  - Constant execution times: pessimism
- IPET based on ILP
  - Augment model with hardware effects
  - Augment objective function with gains/penalties
  - Becomes messy for more than 1 hardware speed-up feature

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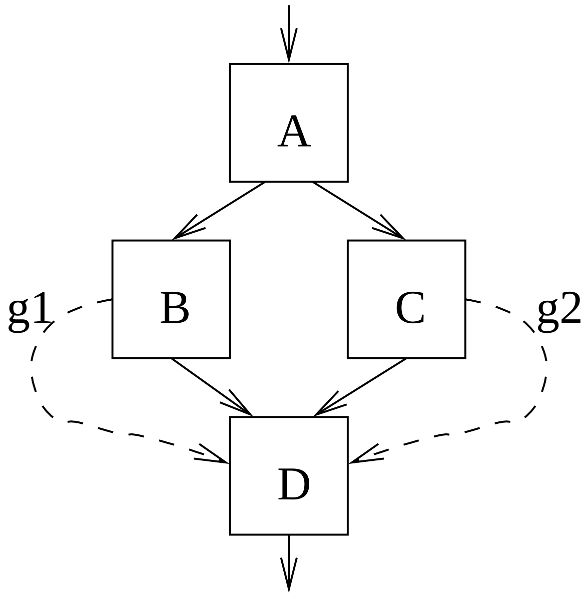
Motivation: Example 1



Blocks

x_A, x_B, x_C, x_D

c_A, c_B, c_C, c_D

$c_D \in \left\{c_{D/B}, c_{D/C}\right\}$

$c_{D/B} = \widehat{c}_D - g_1$

$c_{D/C} = \widehat{c}_D - g_2$

Gains

$x'_1 = x_{BD}$

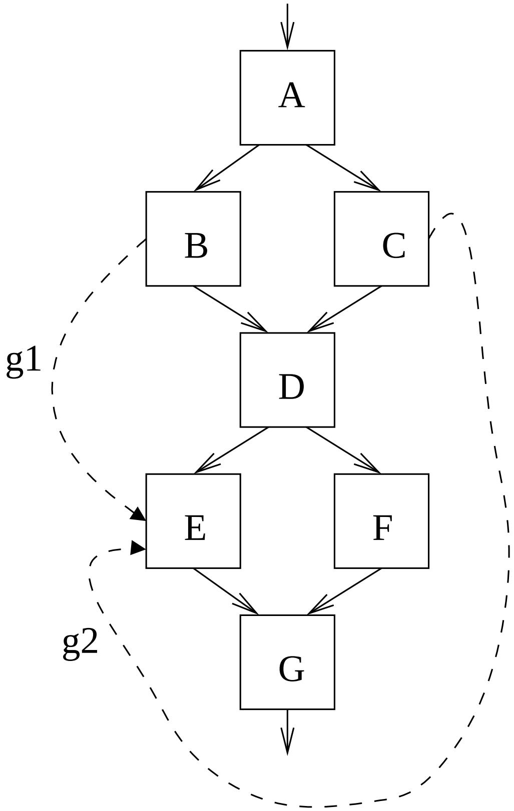
$x'_2 = x_{CD}$

$c'_1 = g_1$

$c'_2 = g_2$

$$f = max(\sum_{i=A}^{D} x_i \times c_i + \sum_{j=1}^{2} x'_j \times c'_j)$$

Motivation: Example 2



Blocks

$x_A, x_B, x_C, x_D, x_E, x_F, x_G$

$c_A, c_B, c_C, c_D, c_E, c_F, c_G$

$c_E \in \{c_{E/B}, c_{E/C}\}$

$c_{E/B} = \widehat{c} - g_1$

$c_{E/C} = \widehat{c} - g_2$

Gains

$x'_1 = x_{BDE} = ?$

$x'_2 = x_{CDE} = ?$

$c'_1 = g_1$

$c'_2 = g_2$

$$f = max(\sum_{i=A}^{G} x_i \times c_i + \sum_{j=1}^{2} x'_j \times c'_j)$$

Motivation: Summary

- The problem of modeling the variablity in execution times using ILP reduces to the problem of mapping the x' variables to some x variables in the model
  - The mapping is straight forward in Example 1: The effect of B on D occurs whenever B executes
  - The mapping in Example 2 is not obvious
  - Ermedahl suggested bounding the effect from top and bottom
    - Tedious if affected block far from affecting block
    - Because ILP is not path-sensitive, negative effects can be included in the final solution without the block sequences causing them
    - This causes pessimism
- Need to include some path-sensitivity
  - A particular execution time of some basic block only occurs given some block has executed before
  - e.g. $x_B > 0 \Rightarrow c_D = 10$ (Example 1)

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A Solution Using ILP

- ILP supports conjunction and negation only
- Disjunction is supported through model duplication
- We can implement path-sensitivity through mutual exclusive constraints
  - Implications become disjunctions
  - $(x_B > 0 \Rightarrow c_D = 10) \Leftrightarrow (x_B \leq 0 \vee c_D = 10)$
  - Solve all instances of the disjunctive ILP
  - a model with n disjunctions solved in at least 2^n runs
- exponential behaviour

CLP, PWA

- Use Constraint-Logic Programming
  - Conditional execution times expressed through implication
- This yields Predicated WCET Analysis
  - *Performing WCET analysis by considering all different execution times of a program segment and expressing them as the outcomes of executing some other segments in the past*
- Derive constraints
  - Find segments that affect execution time of current segment
  - Link these effects to execution times
- Solve model using CLP

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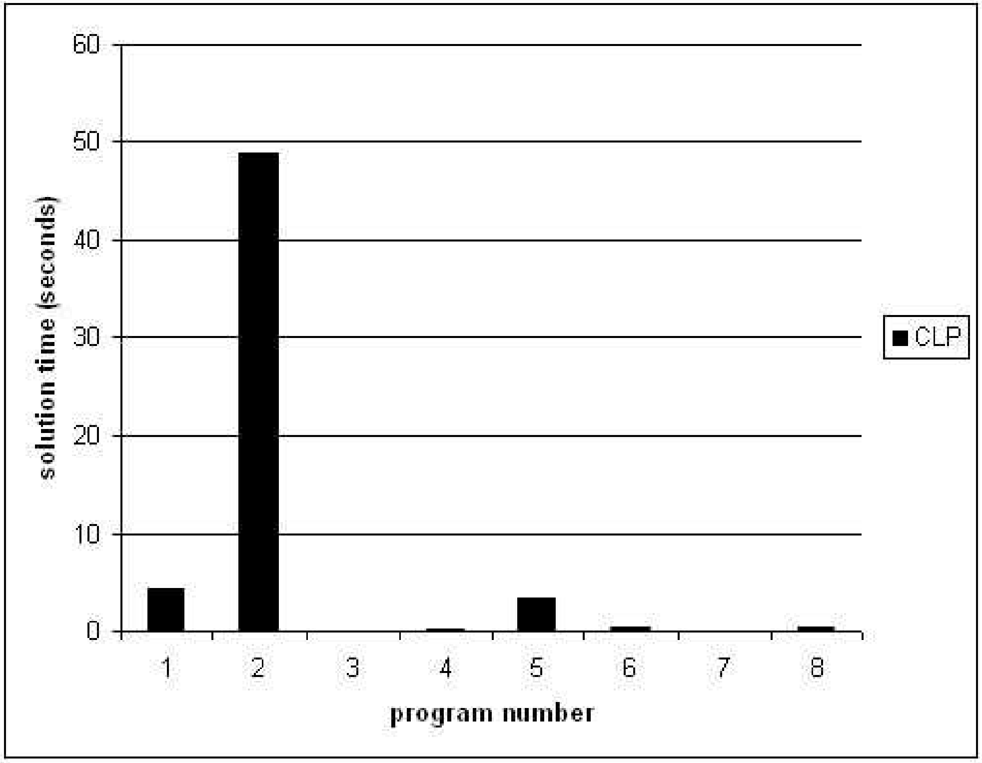
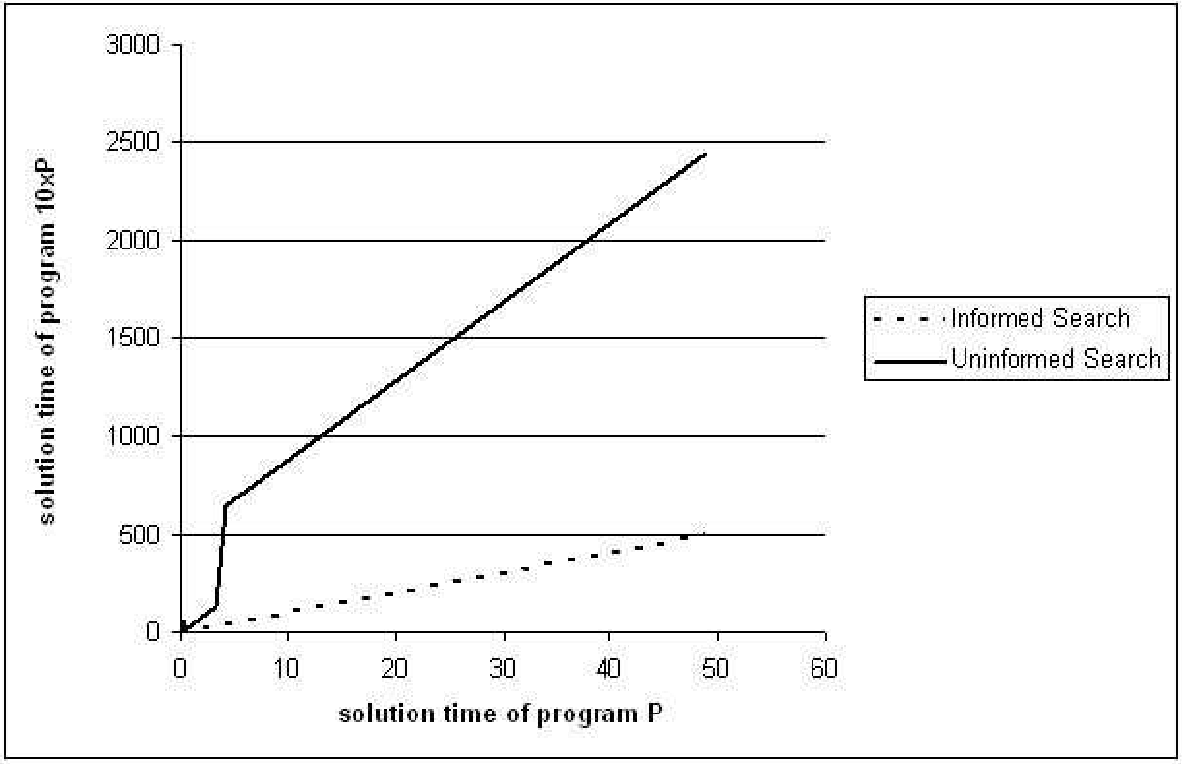
Results: Tightness

program	blocks	implications	wcet		gain
			HMU	PWA	
select	40	27	558627	432803	22.6%
cover	599	2593	44801	38081	15%
fdct	12	6	77759	66975	15%
fir	17	4	87822	81742	7%
lms	134	86	747776	724752	4.3%
cnt	36	2	94672	92912	1.9%
bsort	20	4	58179	57539	1.2%
ns	22	5	892708	888148	0.6%

Results: Solution Time - Uninformed Constraint Search



Results: Solution Time & Scalability



Summary/Conclusions

- Presented predicated WCET Analysis
- Logic programming can be used to model execution dependencies
- Hardware analysis integration rendered possible
- Enforces path-sensitivity in execution times
- ILP not powerful enough to handle execution time variations
- if model has a manageable number of disjunctions, use ILP, otherwise CLP
- Also use CLP to handle unusual flow facts e.g. A xor B or not C

Current Work

- Deriving constraints from traces
- Performing WCET coverage
- Implementing search procedures to solve constraints more efficiently
- Investigating the scalability of the approach