Traces as a Solution to Pessimism and Modeling Costs in WCET Analysis

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July 1st 2008

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- *pessimism*...
  - Can we get almost exact results?
  - Even for complex CPUs, e.g. superscalar out-of-order?
- *static modeling costs*...
  - Can we use a CPU as its own static model without compromising *safety*?

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- but make such operation fully predictable,
    - so timings can be determined safely by measurement,
    - and so the WCET analysis model won't include any pessimistic assumptions.

How to proceed

Two strategies have been considered:

- *Trace scratchpads*, in previous work.
  - Microcode is used to implement predictable execution.

    J. Whitham and N. Audsley, Using trace scratchpads to reduce execution times in predictable real-time architectures, Proc. RTAS, 305–316, 2008.
- *Virtual traces*, in ongoing work.

Both share the common paradigm of a *trace*.

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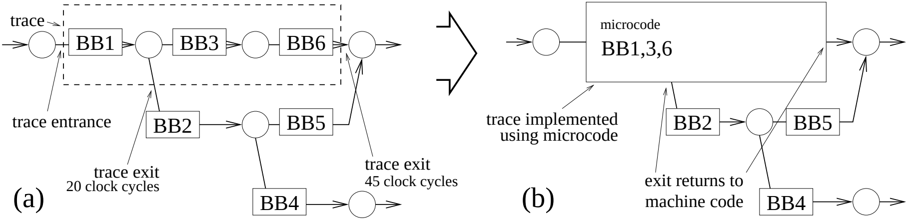


What's a virtual trace?

A virtual trace attempts to deal with issues that are specific to trace scratchpads and their use of microcode, such as

- need for a custom CPU with writable microcode store,
- need for a CPU-specific compiler to generate microcode,
- poor code density of microcode.

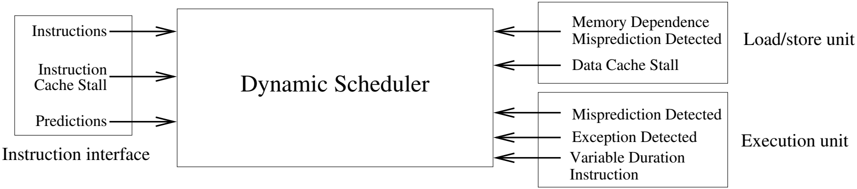
Solution: replace microcode with a virtual trace that controls a conventional *but constrained* dynamic CPU scheduler.

How is it implemented?

1. Regard the CPU dynamic scheduler as a decoder:

$$\textit{machine code} + \textit{virtual trace} \rightarrow \textit{microcode}$$

2. Handle all events that could change execution times.



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- Use {*your favorite static WCET approach*} for analysis.
- CPU is the model: use measurements to determine execution times for paths.

Example

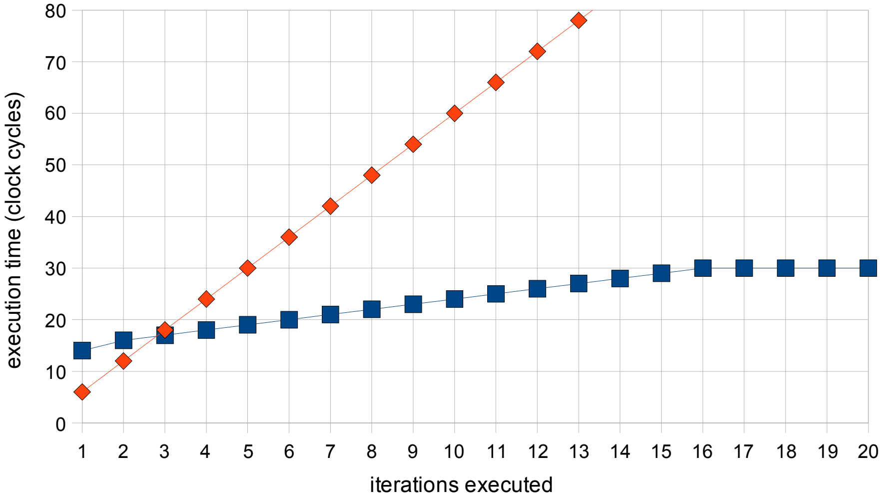
A loop to sum the elements of an array p:

```
for (i=0; i != n; i++)
{
    c += *p;
    p ++;
}
```

This loop has one branch which is assumed taken. The trace *main path* includes L unrollings of the loop body.

Result

With $L = 20$:



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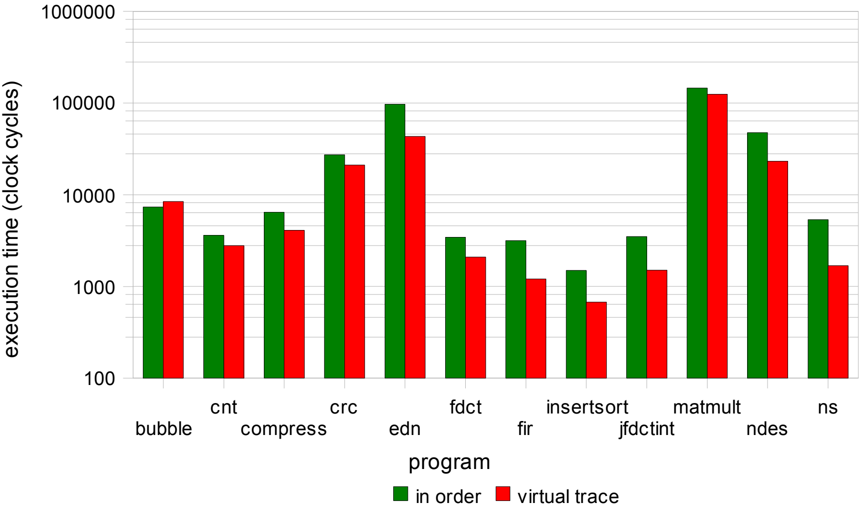
  - Memory effects (forwarding) are a drain on throughput.
- Deterministic memory is assumed.
- WCET analysis models of a program will be more complex, since there may be more than one way to execute a basic block, e.g. due to unrolling.

Preliminary Results



How to reduce costs

Two possible strategies to improve the effectiveness of traces:

1. Consider some branches as both "taken" and "not taken" by converting some code to the *single-path paradigm*.
   - For each branch, WCET analysis will tell us if this will reduce the overall WCET or not.
2. Embed guarantees about forwarding if possible.
   - Difficult in the general case.

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- But how does the paradigm compare to the pessimism and modeling costs of more conventional approaches? Are the CPU modifications really worth doing?
- What would the WCET community like to see next?
- All questions and comments are welcome!
- Further information:
  `http://www.jwhitham.org.uk/pubs/`