Impact of code compression on estimated worst-case execution times

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- This works aims to analyze the impact of code compression on the worst case execution time (WCET)

Current Section

Principles

- Representing the code in a more compact form
  - Reduces storage needs
  - Modifies the effective memory bandwidth
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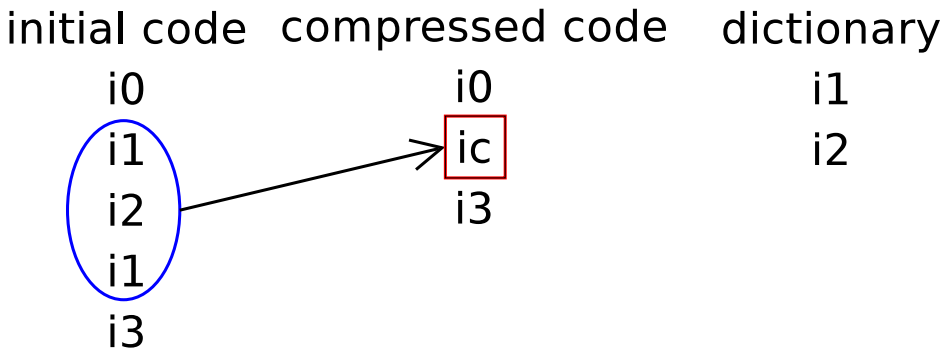
- Decompression during execution
  - Decompression time is critical!
  - How? software/hardware/mix
  - Where? pre-cache/post-cache/in-pipeline

Dictionary based code compression



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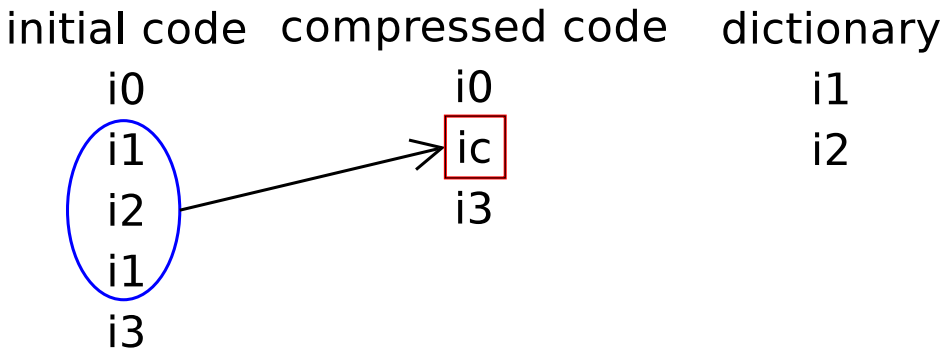

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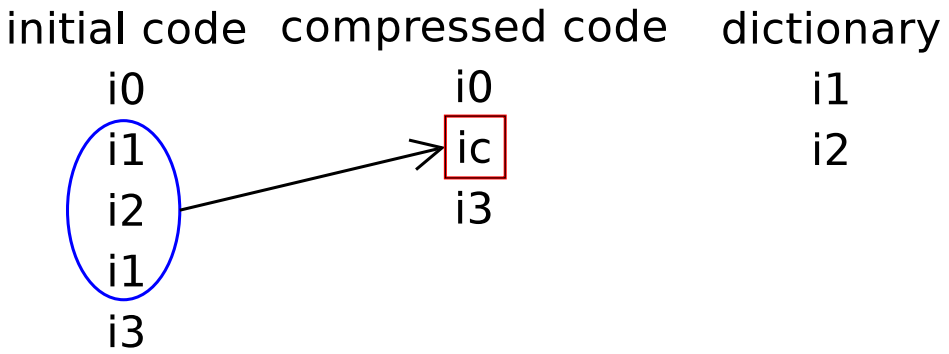

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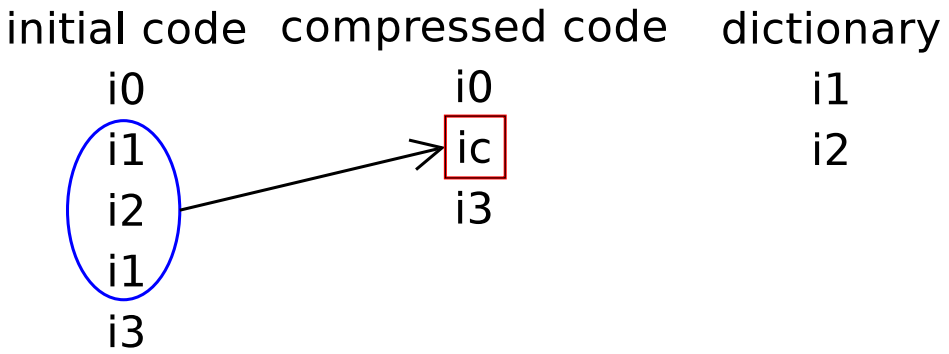

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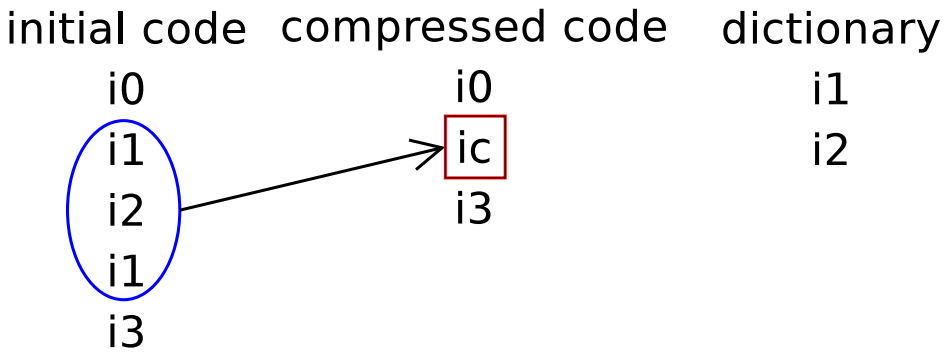

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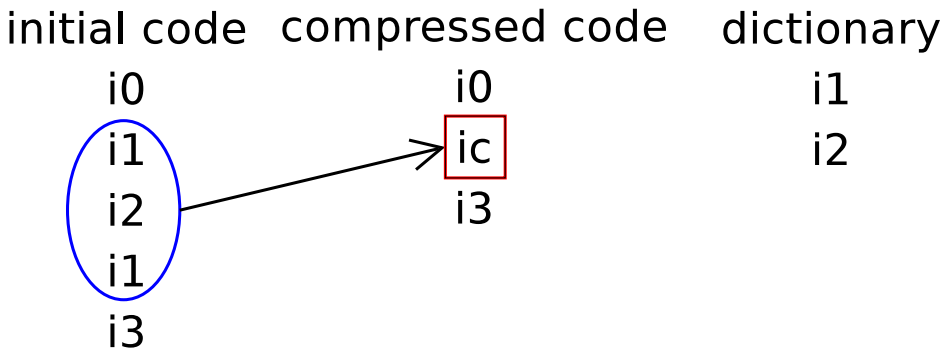

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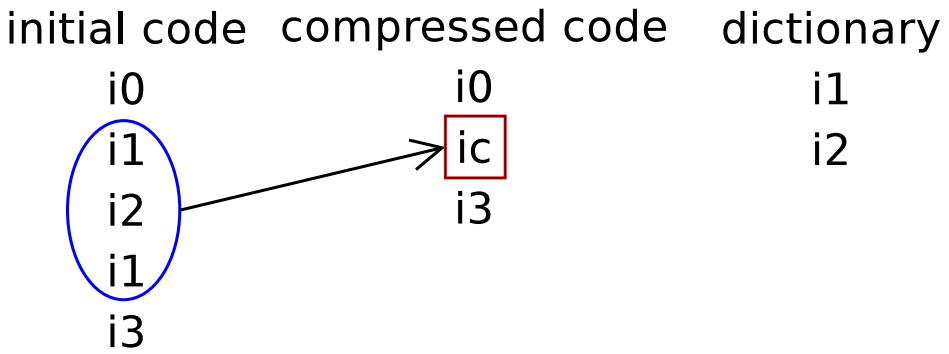

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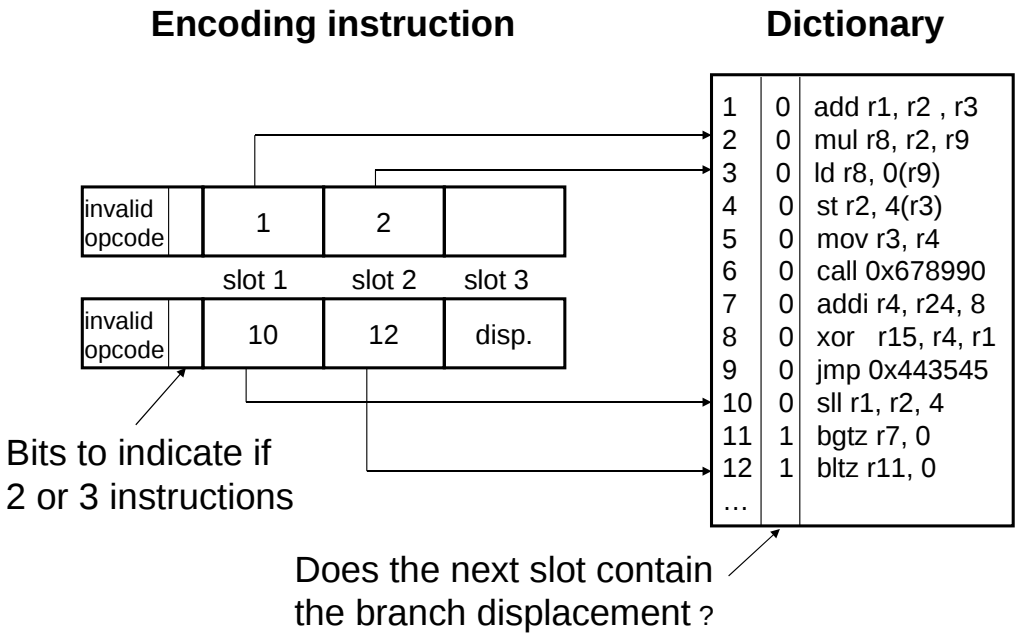
  - Multiple branch targets share the same address
    - Which instruction is the real target?

Encoding instruction and dictionary



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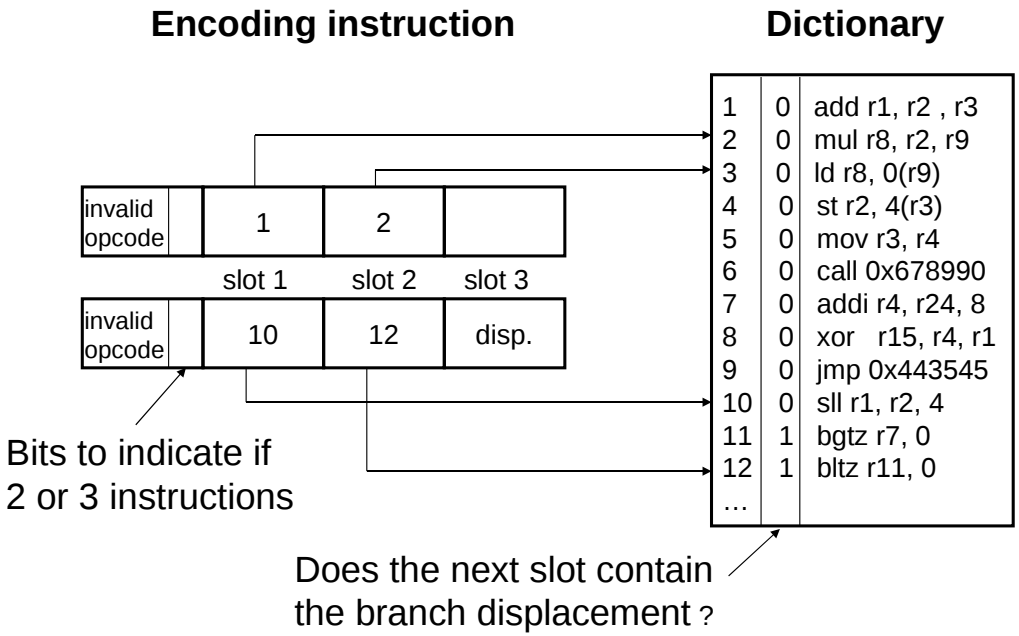

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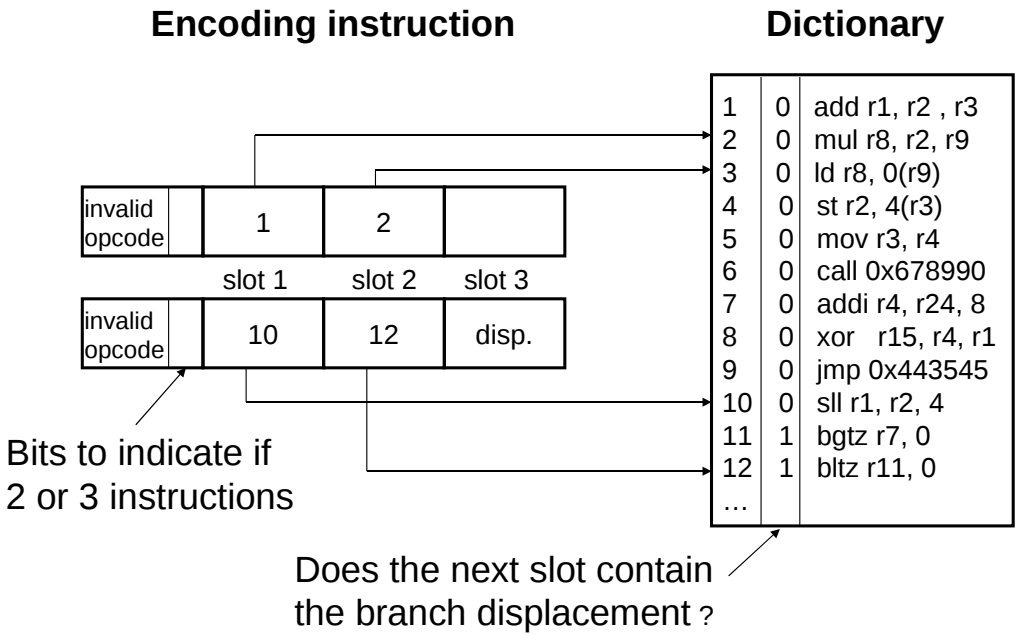

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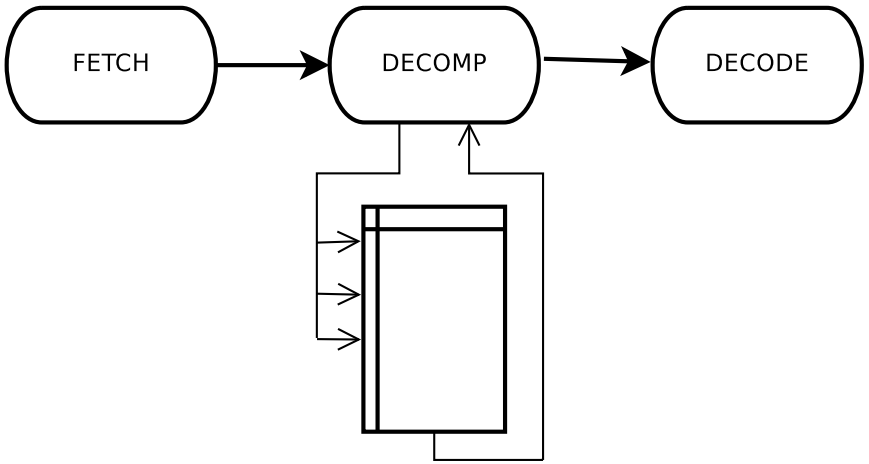
- Dictionary
  - P% is filled with most executed and the remaining is filled with most repeated instructions

In-pipeline decompression



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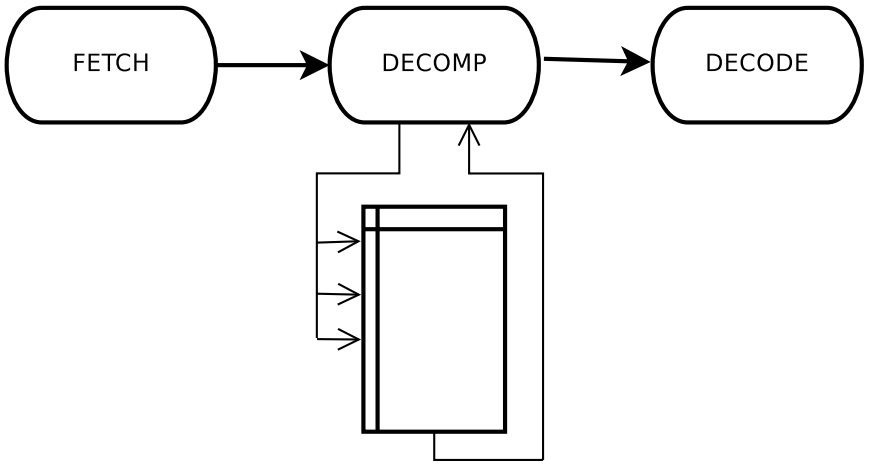

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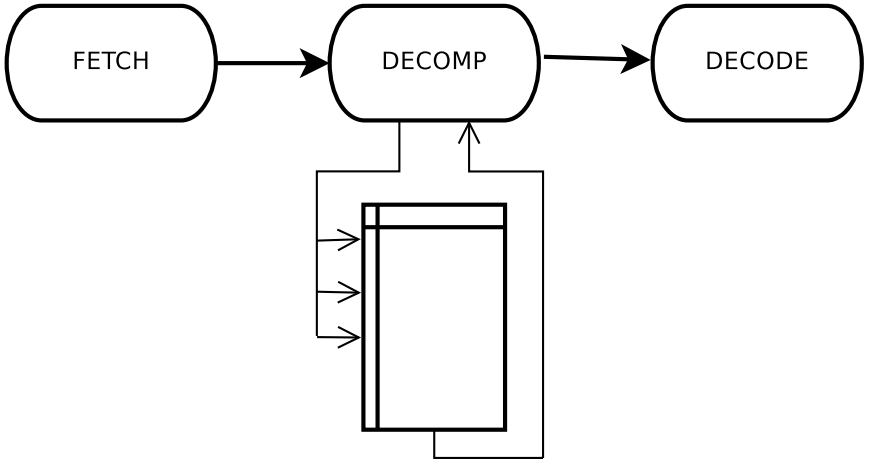

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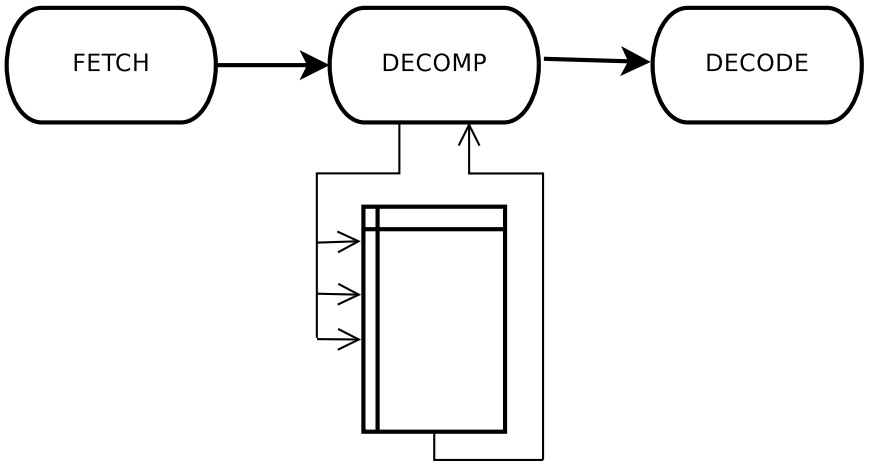

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- Requires modification of the processor core!

Current Section

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- We focus on low level analysis since code compression doesn't change flow facts

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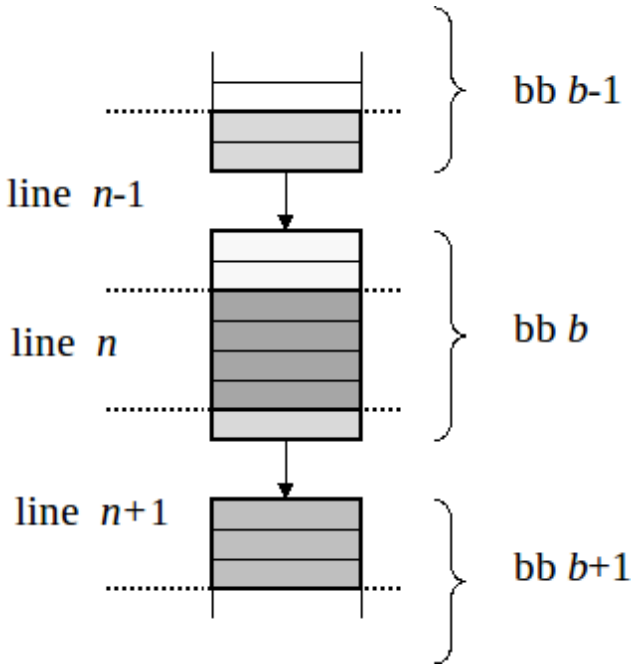

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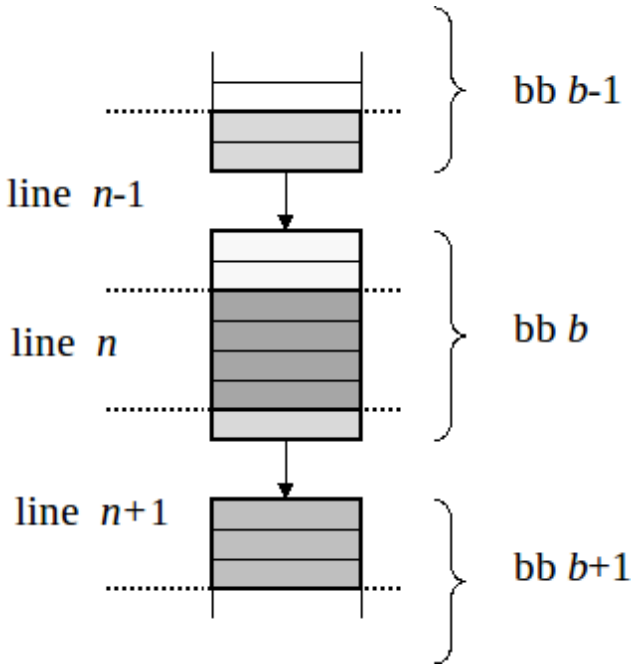

- As a result, each l-block is classified as *Always Hit*, *Always Miss*, *Persistent* or *Not Classified*

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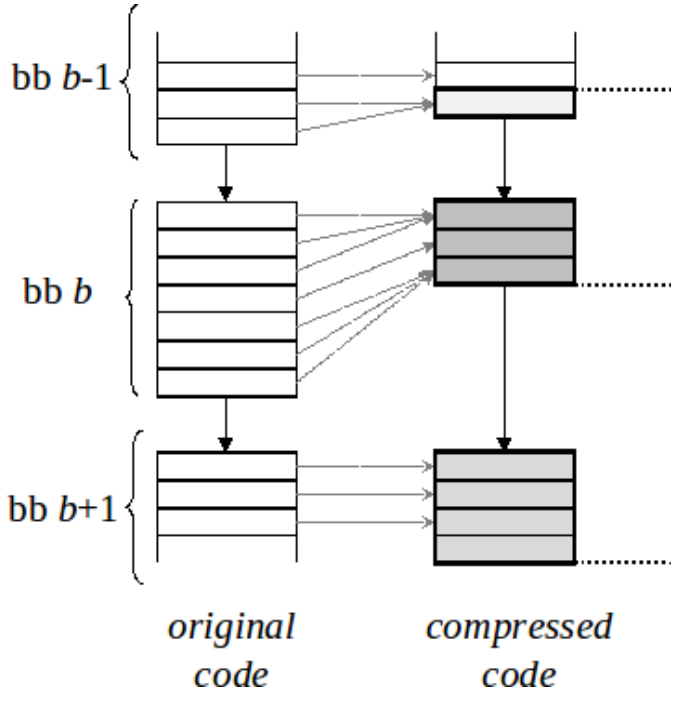

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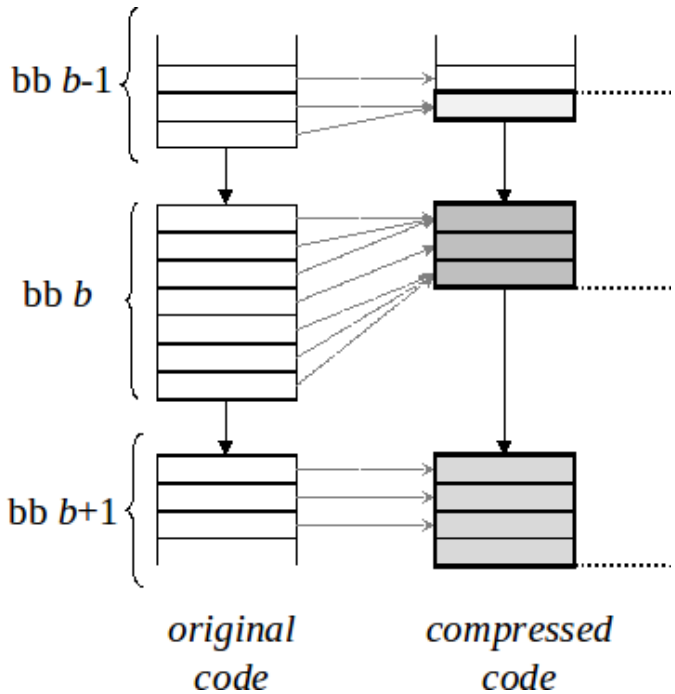
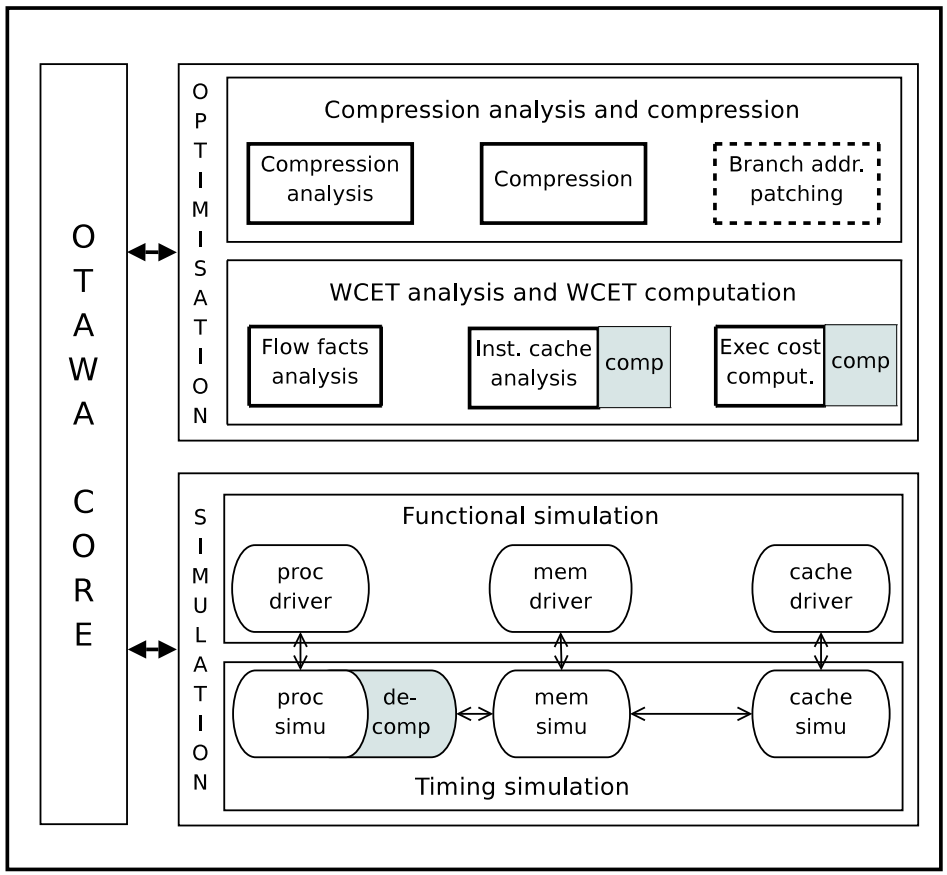


- Effects on the estimated WCETs are hard to predict

Current Section

OTAWA

- OTAWA: Framework for code analysis and simulation (IRIT)
  - Library providing a series of tools for WCET analysis
  - Cycle-level simulator built on the SystemC library



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- WCET is computed considering observed execution counts and estimated execution costs:
  - $WCET = \sum x_{i,j}.c_{i,j}$
    - $x_{i,j}$ is the execution count of two-block sequence $b_i - b_j$
    - $c_{i,j}$ is the maximum cost of block bj in sequence $b_i - b_j$
    - For sequences that include *Persistent* l-blocks, the accuracy is improved by distinguishing between the cost at the first loop iteration and the cost at other iterations

Base configuration

- Processor
  - Two way super scalar
  - In order execution
  - No branch prediction
  - Perfect data cache
  - 10-cycle instruction cache miss penalty
- Compression
  - 75% of the dictionary is filled with most executed instructions
    - $\Rightarrow$ Code compression improves not only code size but also execution time and energy consumption

Benchmarks

- From Mälardalen University website
  - `adpcm`: adaptive differential pulse code modulation
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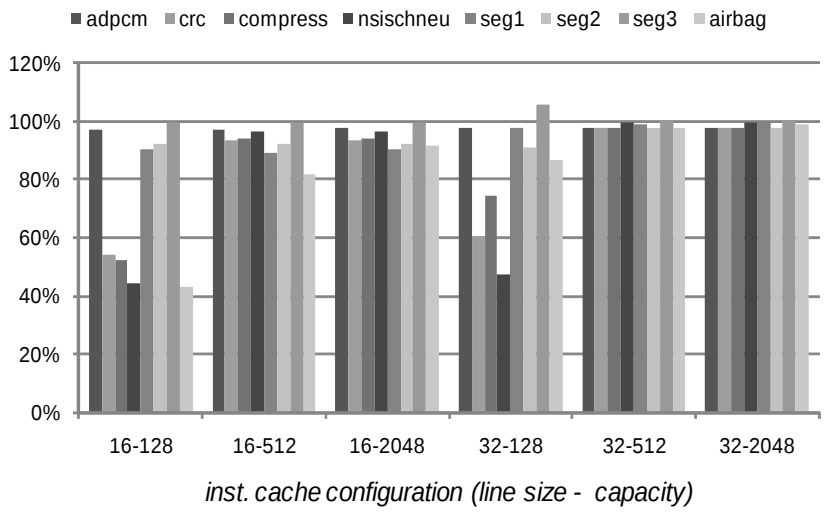
- Developed by IRIT
  - `seg`: image segmentation; includes 3 tasks that are considered as 3 benchmarks
    - `seg1`: finds regions of adjacent similar pixels in the image
    - `seg2`: fuses adjacent regions
    - `seg3`: fuses pixels that belong to fused regions
  - `airbag`: airbag control software

Current Section

Code size

Benchmark	Compression rate	Compression rate incl. dictionary	Compression rate of the main function
adpcm	19.2%	9.5%	21.7%
crc	24.5%	10.4%	53.0%
compress	22.1%	10.1%	33.4%
nsichneu	29.1%	18.4%	43.6%
seg	18.5%	11.3%	n/a
seg1	n/a	n/a	3.0%
seg2	n/a	n/a	2.3%
seg3	n/a	n/a	4.1%
airbag	31.8%	25.1%	42.8%

Observed and estimated worst case execution time



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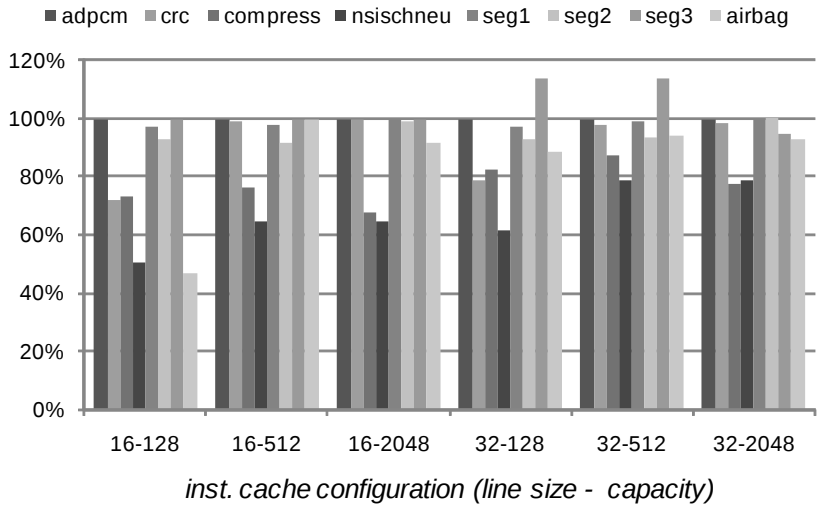
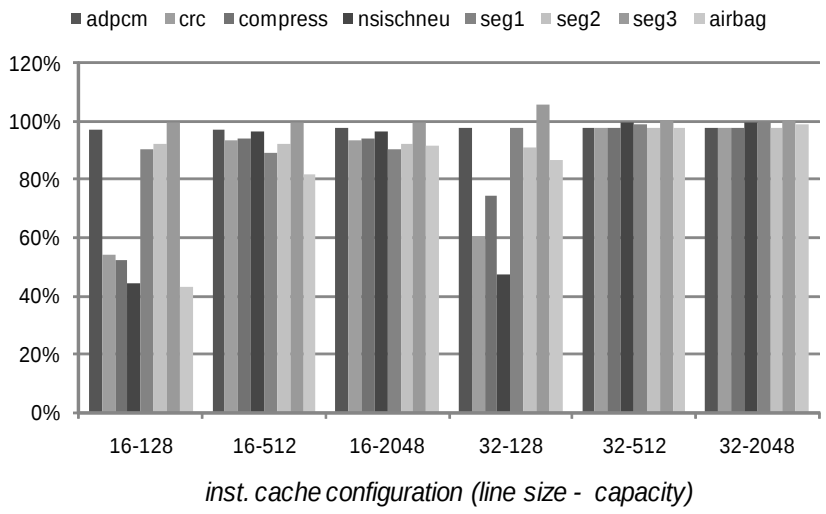
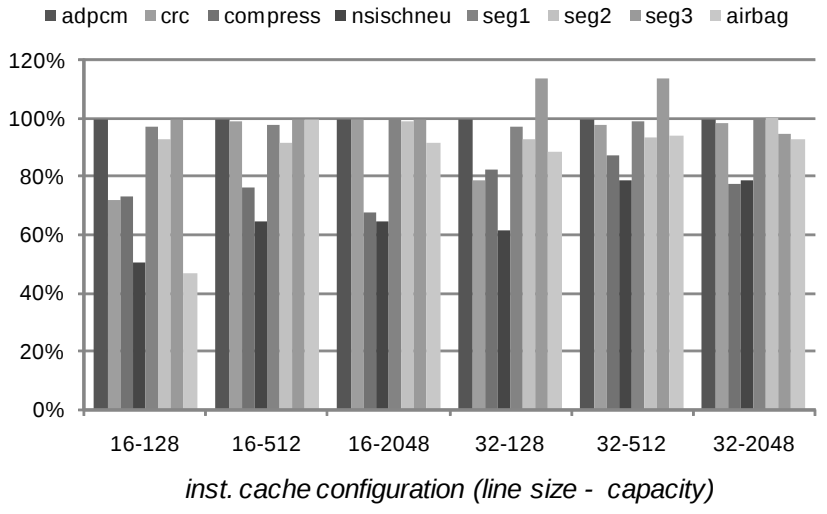


- Worst-case execution time

Observed and estimated worst case execution time

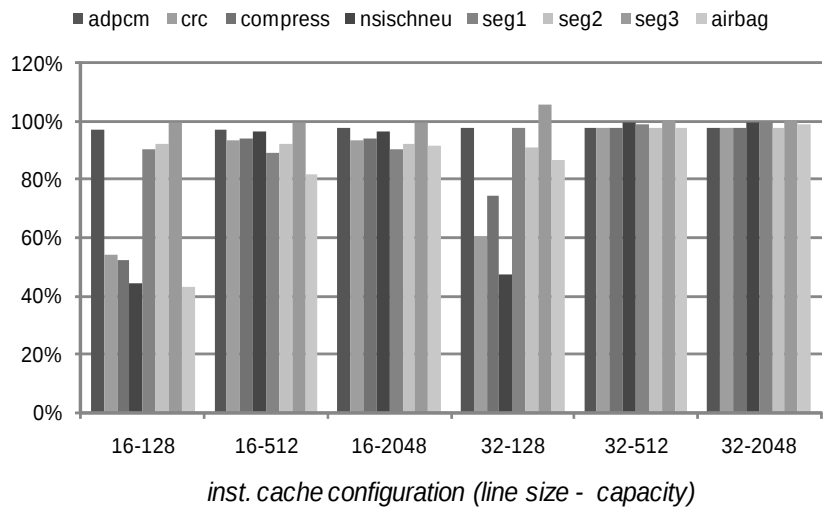


- Observed execution time
  - Decreased particularly for small caches
    - $\Rightarrow$ Reduced cache miss

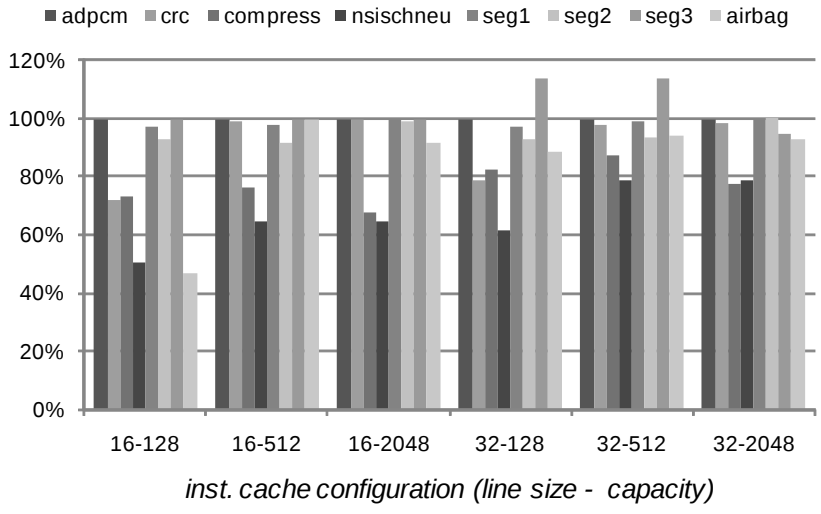


- Worst-case execution time

Observed and estimated worst case execution time



- Observed execution time
  - Decreased particularly for small caches
    - ⇒ Reduced cache miss
  - Increased in one case
    - ⇒ Modified code alignment increased cache accesses



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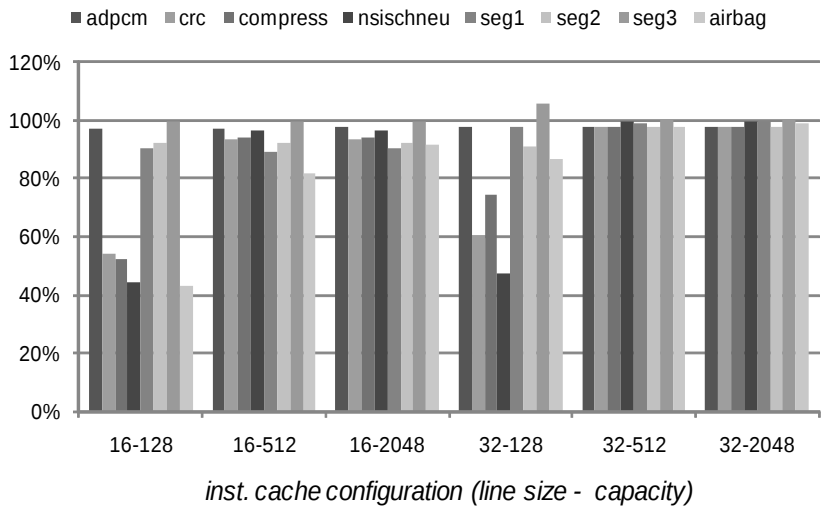

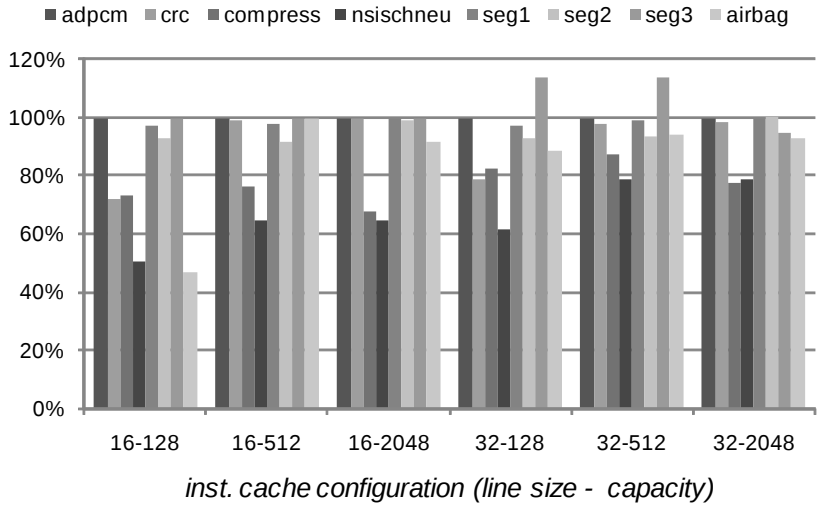

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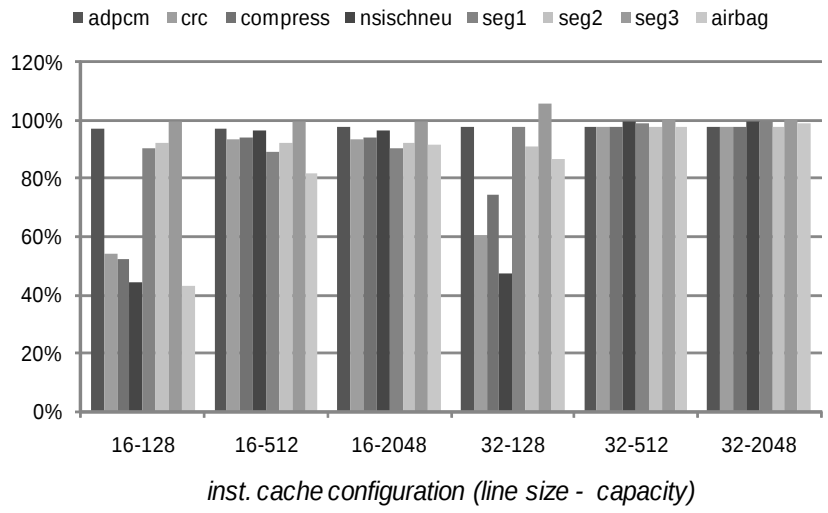

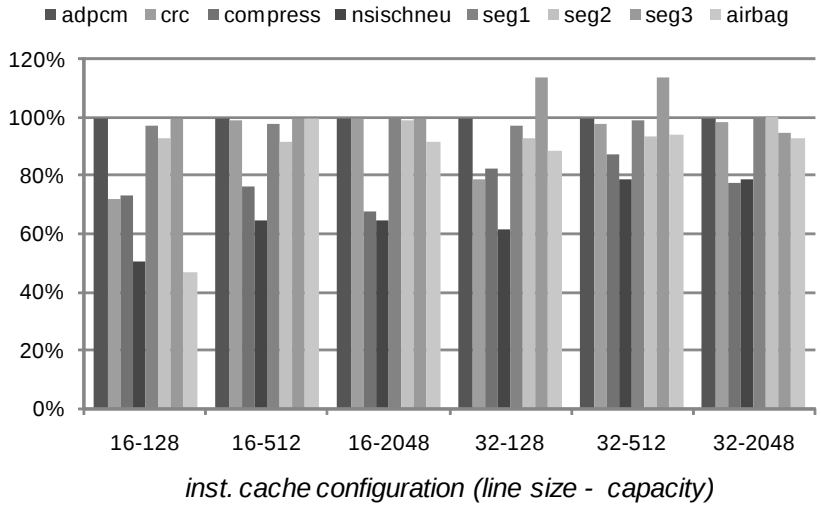

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- Worst-case execution time
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    - $\Rightarrow$ Corresponds to a decrease (increase) of the WCET estimation accuracy

Observed and estimated worst case execution time

	cache size (bytes)					
	line = 16 bytes			line = 32 bytes		
	128	512	2048	128	512	2048
observed	26.0%	7.0%	5.6%	16.0%	1.5%	1.2%
WCET	19.2%	8.6%	8.7%	10.0%	4.4%	6.4%

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- With a perfect instruction cache, estimated WCET of the compressed code is almost the same as the original code
  - $\Rightarrow$ Accuracy of the instruction cache analysis is increased
- For `nsichneu` whose estimated WCET is improved while observed time isn't improved for larges caches
  - Number of *Always Miss* I-blocks is cut by about 45%
  - Number of *Not Classified* I-blocks is cut by 50% to 70%

Current Section

Conclusion and future work

- Code compression reduces instruction cache misses while in-pipeline decompression hides decompression penalty by pipelined execution
  - Improvement on observed and worst case execution times

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- Future work
  - Take into account WCET related information during compression in order to further increase accuracy of the cache analysis

FIN

THANK YOU !!!

Questions?