WCET-aware Software Based Cache Partitioning for Multi-Task Real-Time Systems

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PREDATOR

Outline

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WCET-aware Cache Partitioning

Problem:

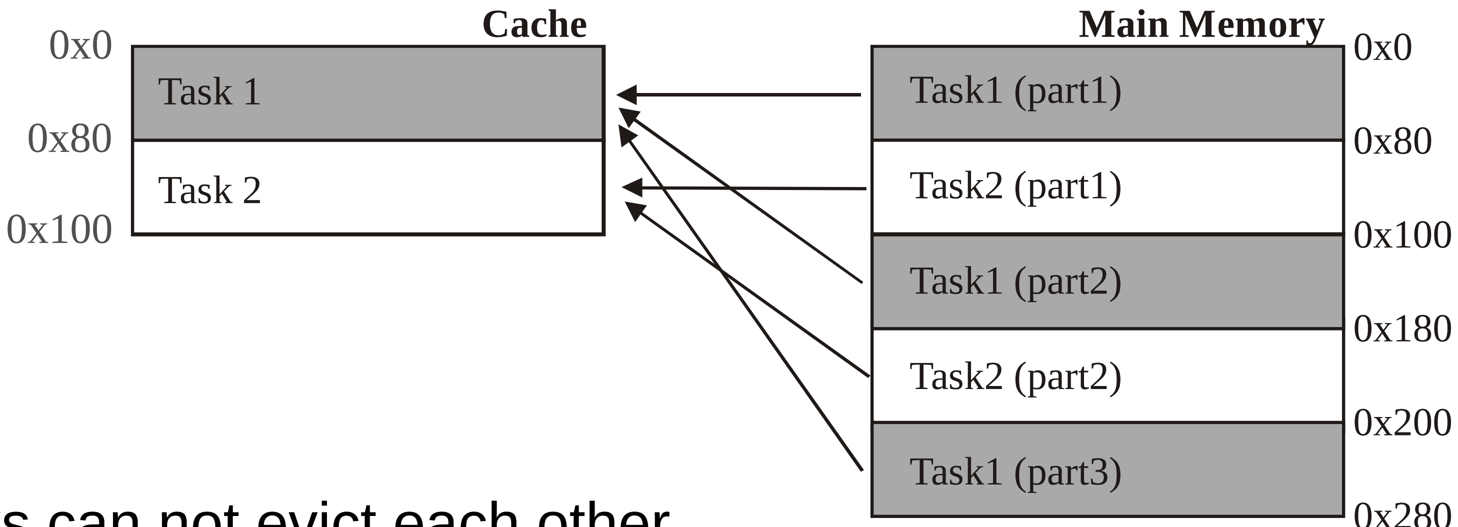
- Caches are a source of unpredictability
- Behaviour in general unpredictable in systems performing preemptive scheduling
- Different tasks could replace each other in cache

Idea:

- Divide the cache into partitions
- Assign one task per partition
- ➢ Tasks can not replace each other

Software Based Cache Partitioning

- Exploit the cache's modulo addressing function
- Distribute tasks in address space
- Ensure mapping to particular cache lines



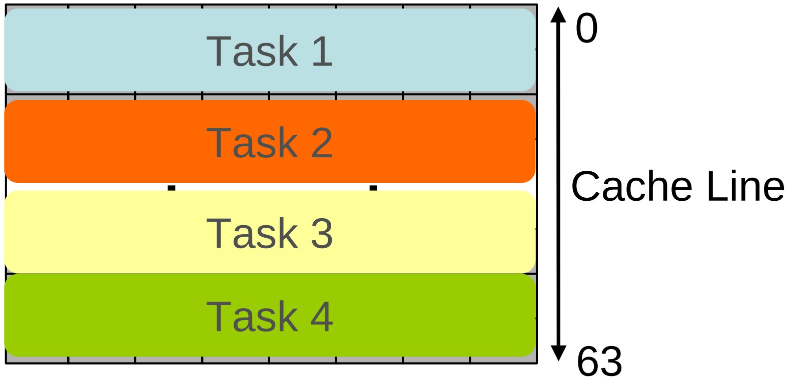
✓ Tasks can not evict each other

− Additional jumps have to be inserted, branches corrected

WCET-aware Cache Partitioning

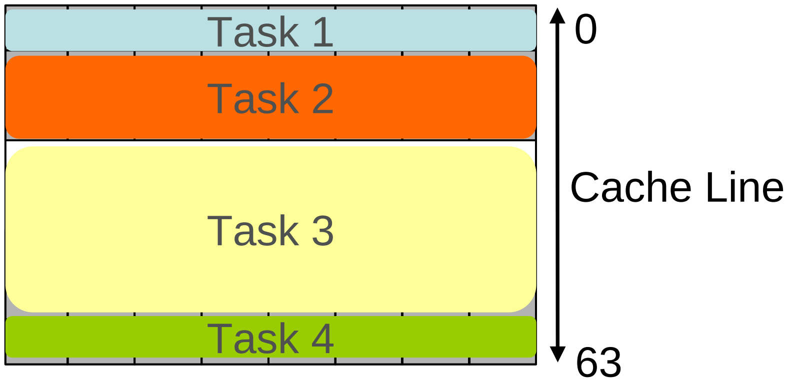
Greedy approach*

- Partition size depends on task's code size
- Example: 4 tasks with the same code size



Better

- Employ an ILP-model to select optimal cache size for every task
- Take execution frequencies into account



[Frank Mueller, 1995: Compiler Support for Software-Based Cache Partitioning]*

ILP Formulation

T : set of periodically scheduled tasks $t_1 \ldots t_m$

P : set of partition sizes $p_1 \ldots p_j$

$$x_{ij} = \begin{cases} 1, \text{ if } t_i \text{ assigned to } p_j \\ 0, \text{ else} \end{cases}$$

$WCET_{ij}$: t_i's WCET if assigned to p_j

I : scheduling interval

c_i : task t_i is executed exactly c_i times during I

$\Rightarrow |I|$ is the Hyperperiod of T (LCM of the tasks' periods)

ILP Formulation

Each task must have a partition assigned:

$$\forall i = 1..m : \sum_{j=1}^{n} x_{ij} = 1$$

Keep track of the cache size:

$$\sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} * p_j \leq S$$

ILP Formulation

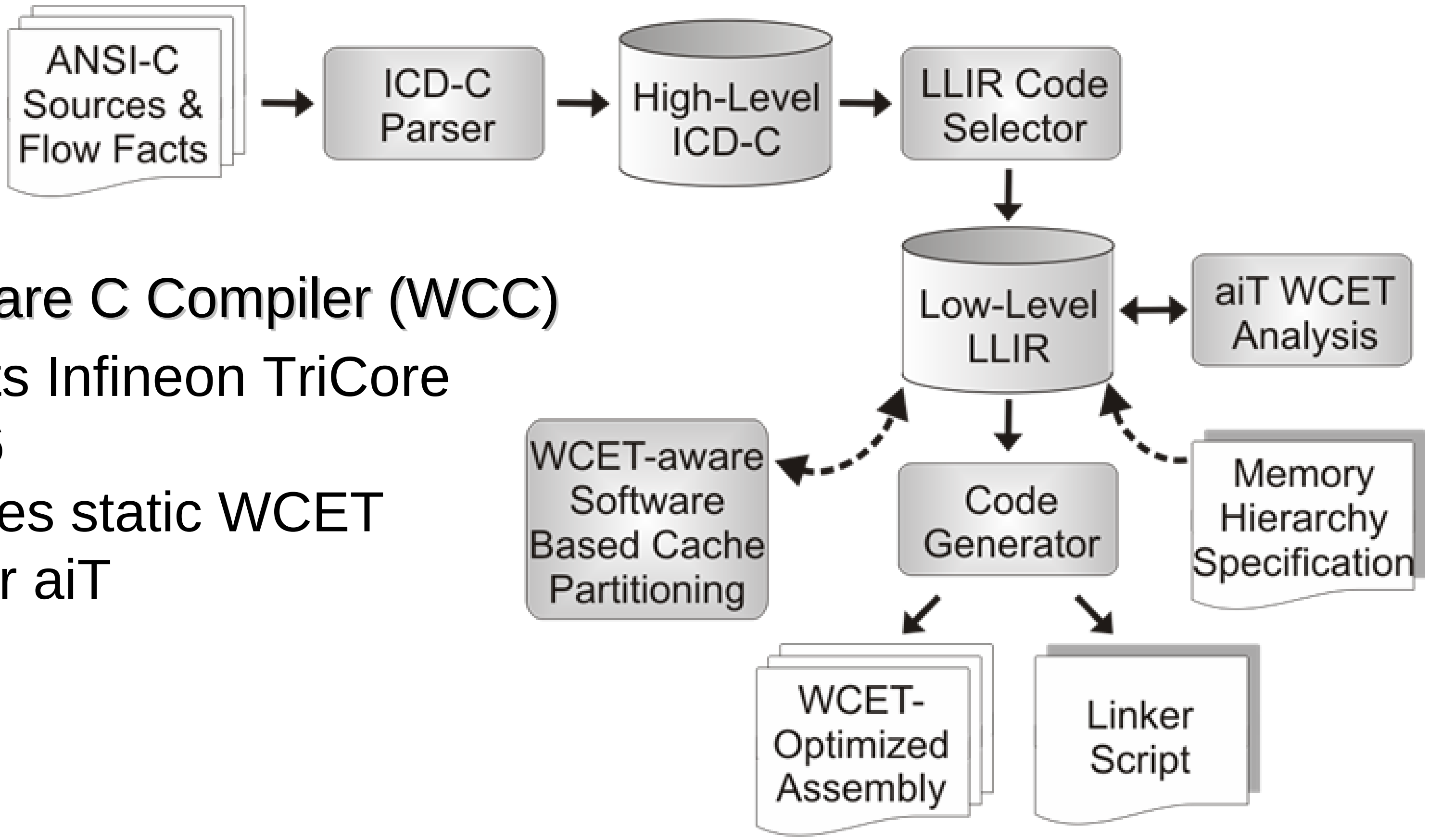
A tasks WCET is determined:

$$WCET(T_i) = \sum_{j=1}^{n} x_{ij} * WCET_{ij}$$

Objective function to minimize:

$$WCET = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} * c_i * WCET_{ij}$$

Workflow



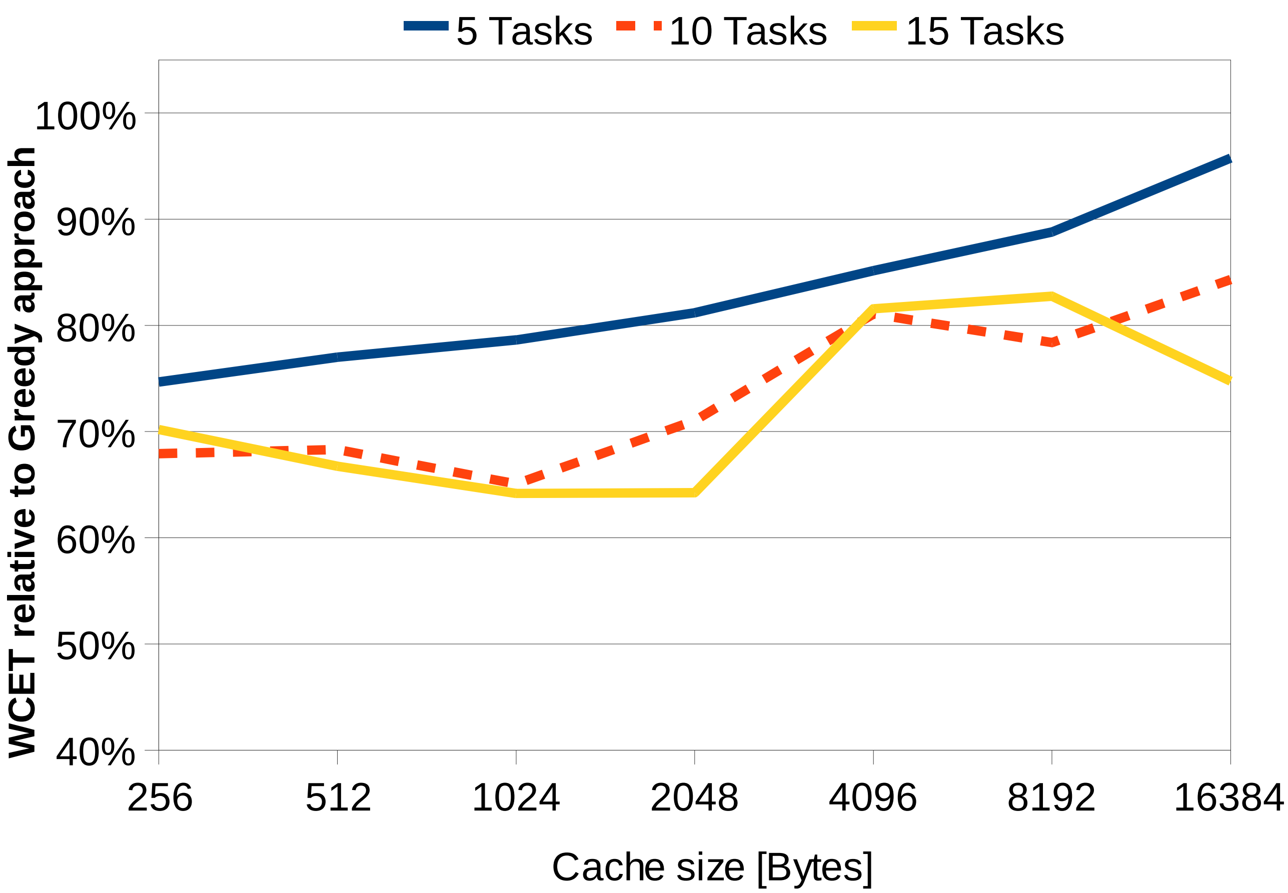
WCET-aware C Compiler (WCC)

- Supports Infineon TriCore TC1796
- Integrates static WCET analyzer aiT

Results: UTDSP

Average of 100 sets of randomly selected tasks:

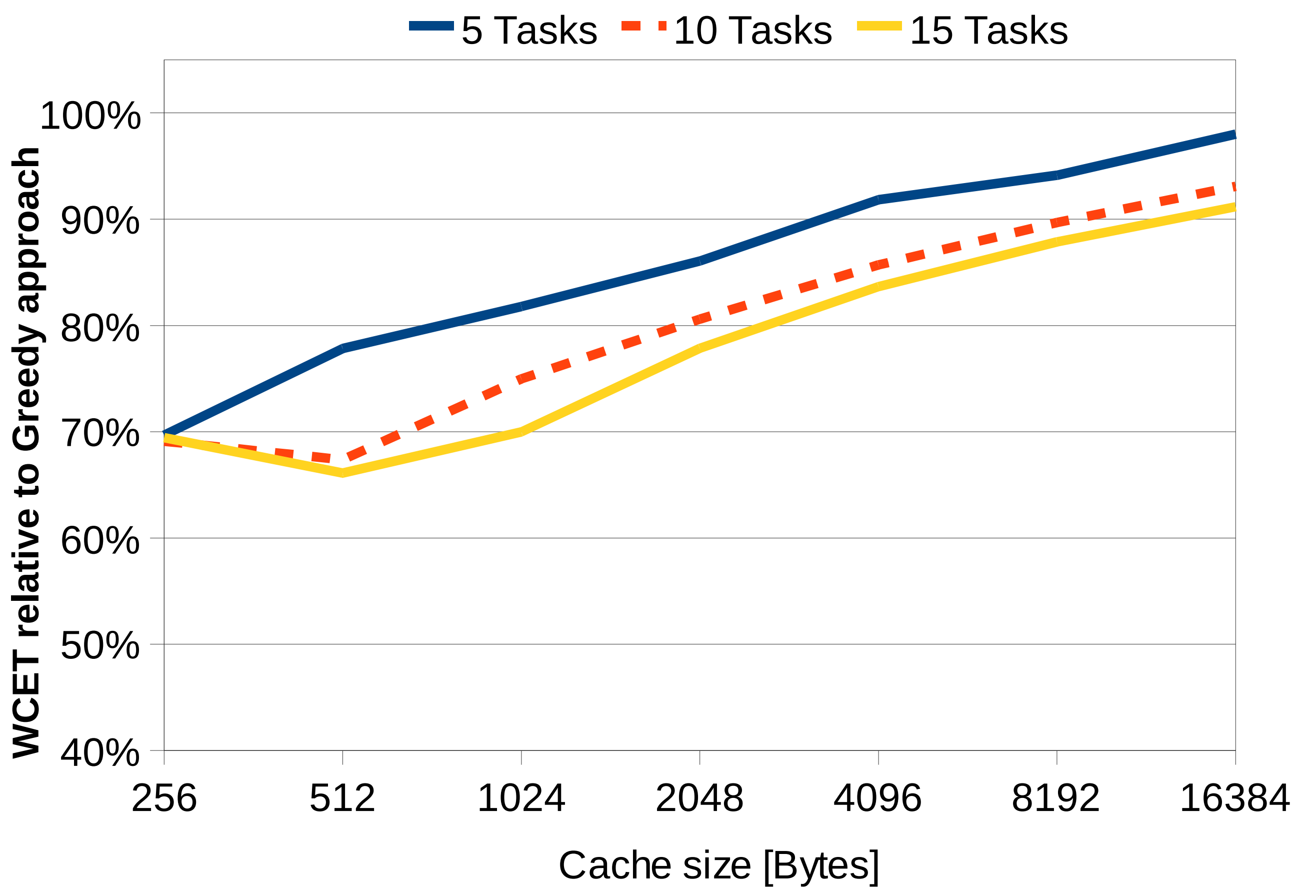
- 5 tasks: ~8kB
- 10 tasks: ~18kB
- 15 tasks: ~26kB



Results: MRTC

Average of 100 sets of randomly selected tasks:

- 5 tasks: ~6kB
- 10 tasks: ~12kB
- 15 tasks: ~19kB



Conclusion

- WCET-driven Cache Partitioning presented
- Employed an ILP to select optimal partition sizes w.r.t. the overall system‘s WCET
- Partitioning introduces predictability for preemptive scheduled systems
- Average WCET reduction of 12% (5 tasks) up to 19% (15 tasks) compared to greedy approach

Future Work

- Tightly coupling of offline schedulers
- Take task dependencies into account

Thank you for your attention!

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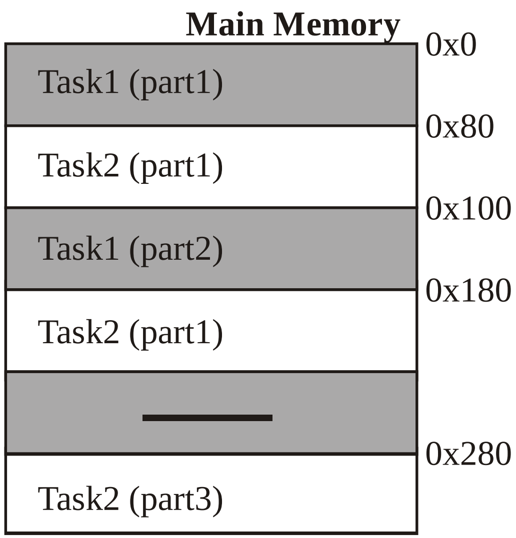
Questions?

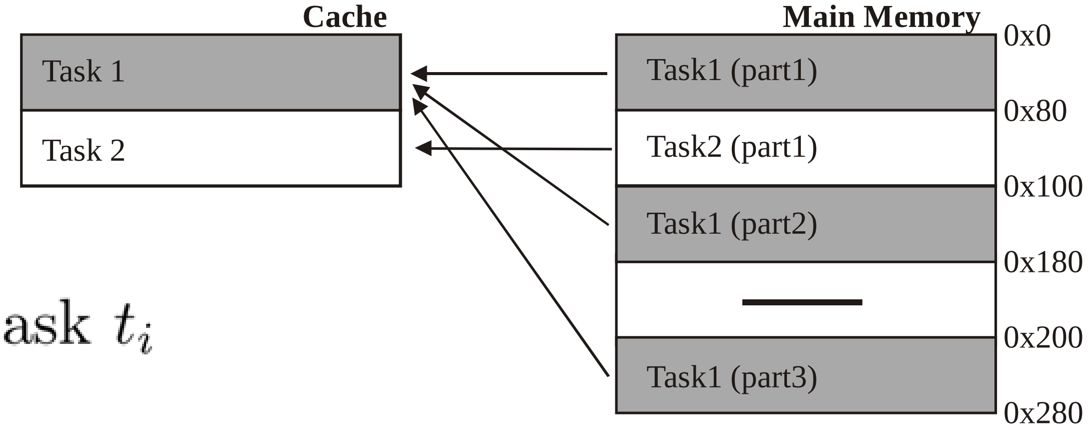
Distribution of Code

- Achieved by exploiting the linker
- Each portion is assigned to its own section
- Example linker script for two tasks:

```
.text: {
  _text_begin = .;
  *(.task_part1)
  . = _text_begin + 0x80;
  *(.task2_part1)
  . = _text_begin + 0x100;
  *(.task1_part2)
  . = _text_begin + 0x180;
  *(.task2_part2)
  . = _text_begin + 0x280;
  *(.task2_part3)
} > PFLASH-C
```



Memory usage



$s(t_i)$: size of task t_i

$p(t_i)$: partition size of task t_i

$$\#partitions(t_i) = \frac{s(t_i)}{p(t_i)}$$

$$S_{Flash} \geq S_{Cache} * max(\#partitions(t_i))$$

$$S_{waste} = S_{Flash} - \sum_{i=1}^{n} s(t_i)$$

Optimization Time

- Host machine: Dual Xeon L5420 @ 2.50GHz
- Using a single core
- Complete workflow consists of:
  - Compilation : up to 3 minutes
  - Analysis : up to 1 hour / task
  - Optimization: up to 1 minute