Energy-Optimal Computing in the AI Age: *Where We Are, Where Can We Go*

Christos Lamprakos
PhD Student
cplamprakos@microlab.ntua.gr

Better: **Software Execution**

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Where We Are, Where Can We Go

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Why bother?

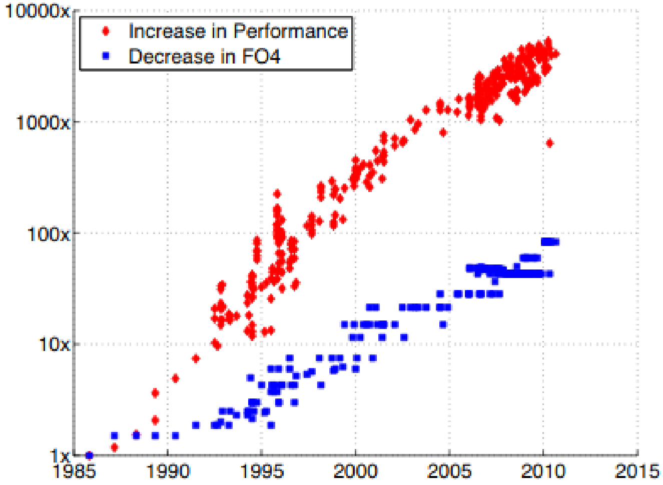

Figure 1.1.1: Improvement in microprocessor and gate performance vs. year.

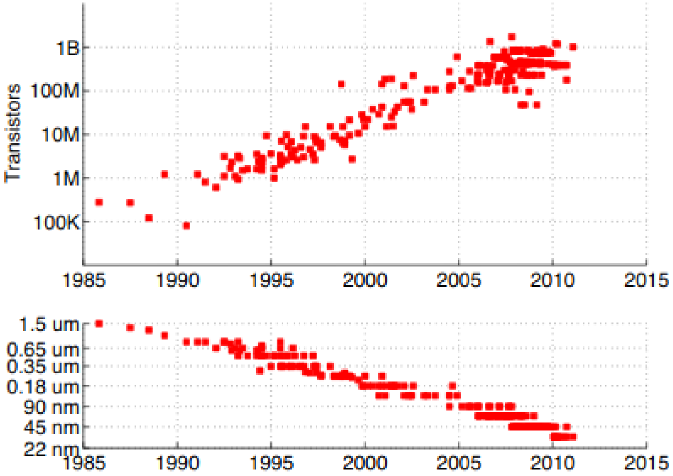

Figure 1.1.2: Number of transistors and feature size vs. year.

Horowitz, M. (2014, February). 1.1 computing's energy problem (and what we can do about it). In 2014 IEEE International Solid-State Circuits Conference Digest of Technical Papers (ISSCC) (pp. 10-14). IEEE.

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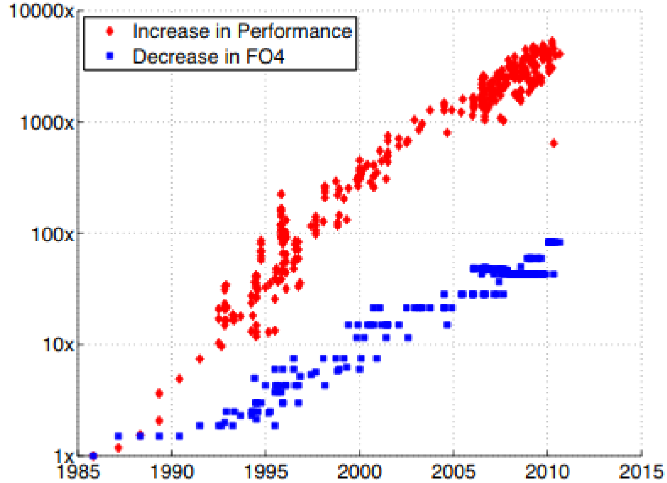

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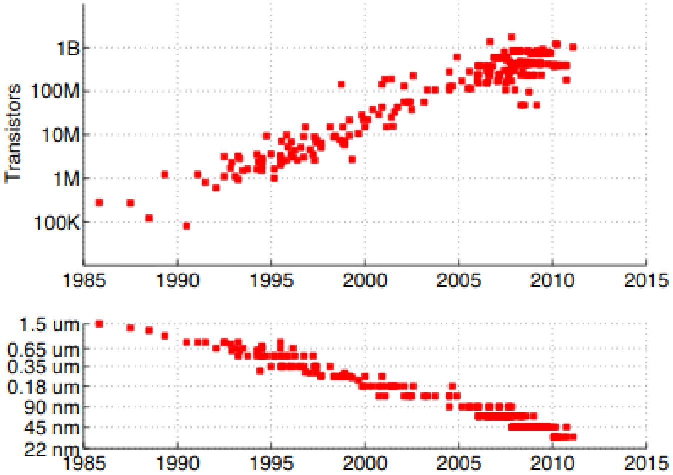

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Performance has scaled well . . .

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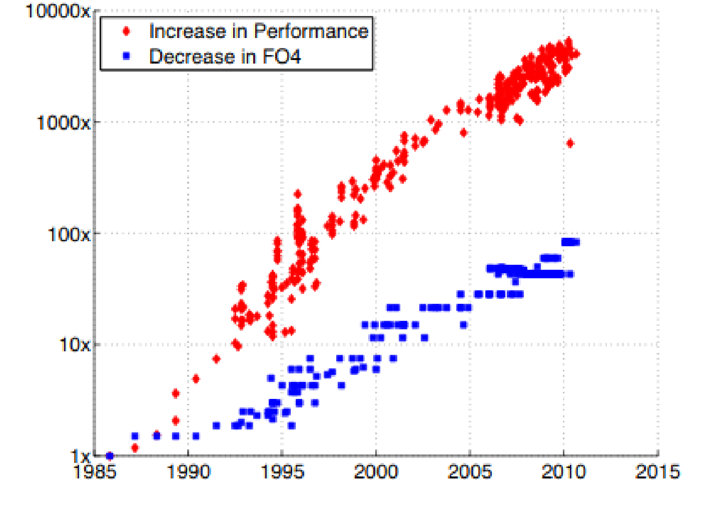

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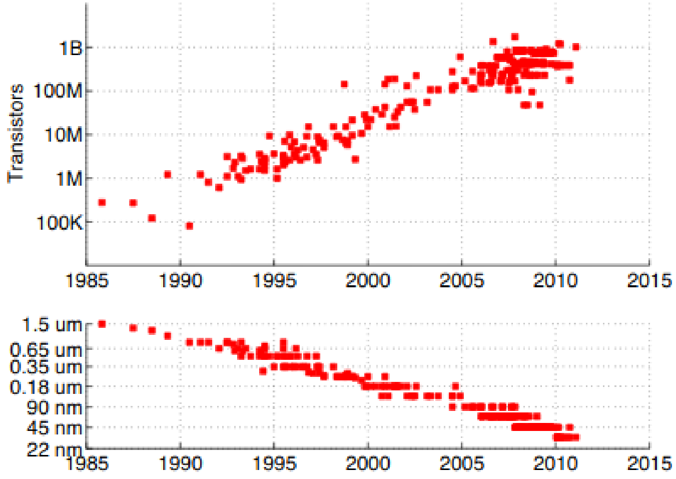

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Transistors got
more + smaller . . .

Performance has scaled well . . .

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. . . BUT:

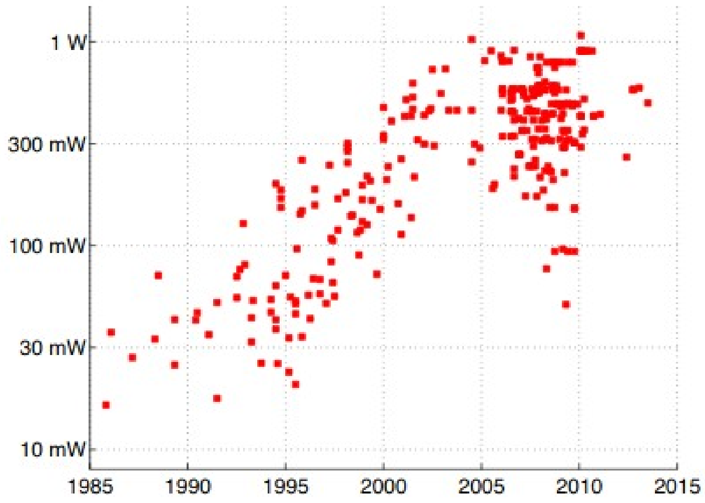

Figure 1.1.3: Power density in mW/mm² vs. year.

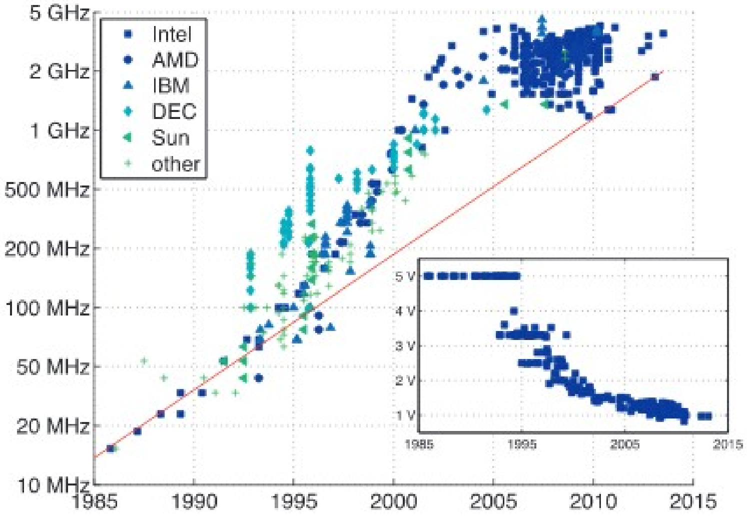

Figure 1.1.4: Clock frequency vs. year. The red line indicates frequency increase due to gate speed. The insert plot is Vdd vs. year.

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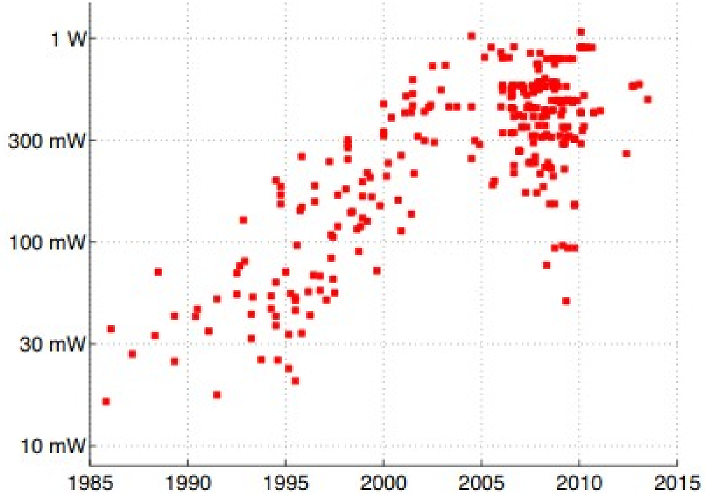

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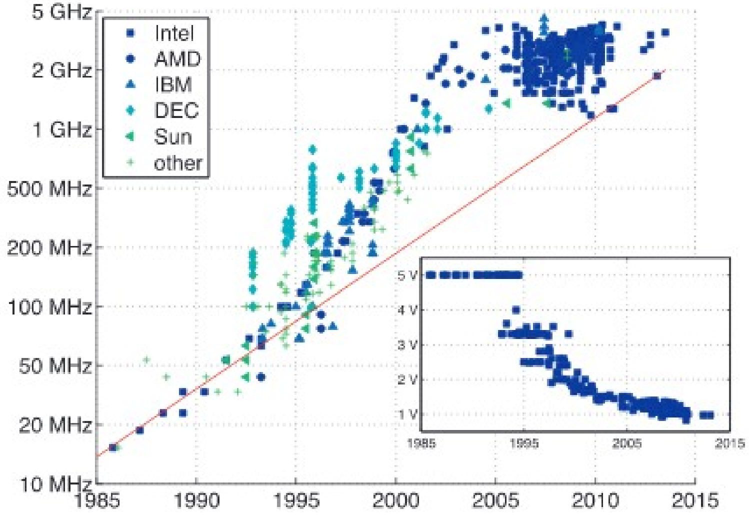

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We hit the power wall!

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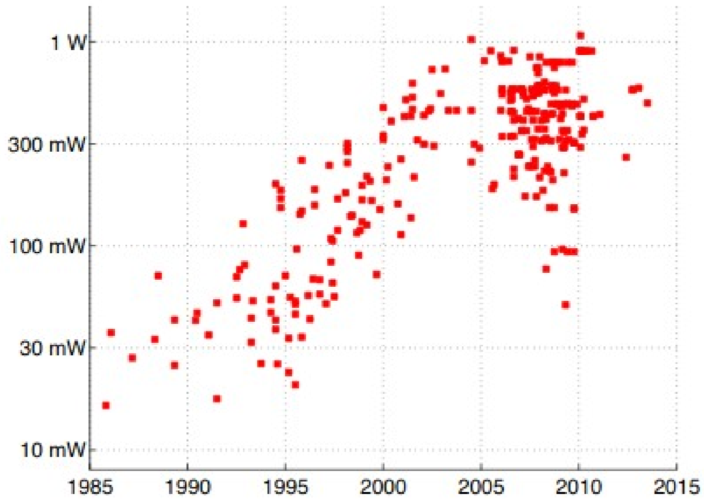

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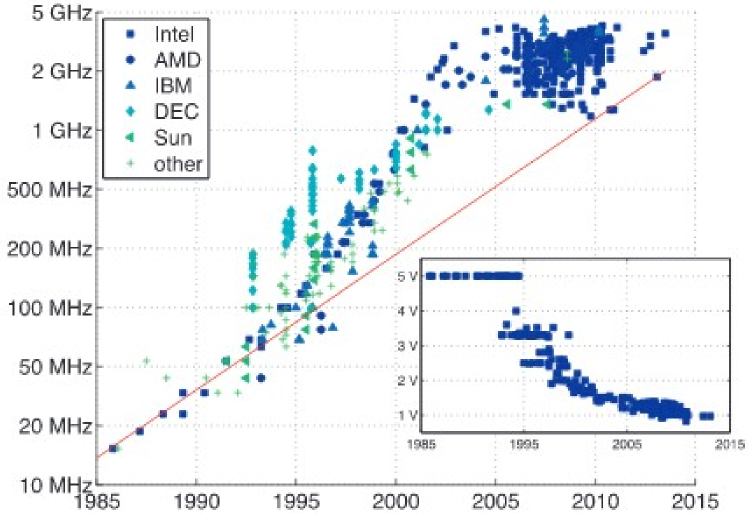

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Which means:
it was time for
multiple cores
per chip

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All is well on the performance front

- Performance := Chip throughput

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- But what about the energy?

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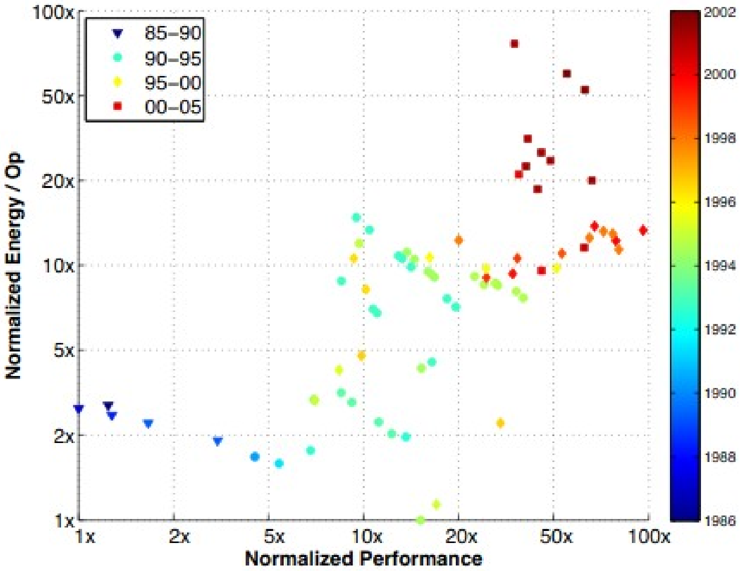

Figure 1.1.5: Instruction energy vs. peak performance (normalized).

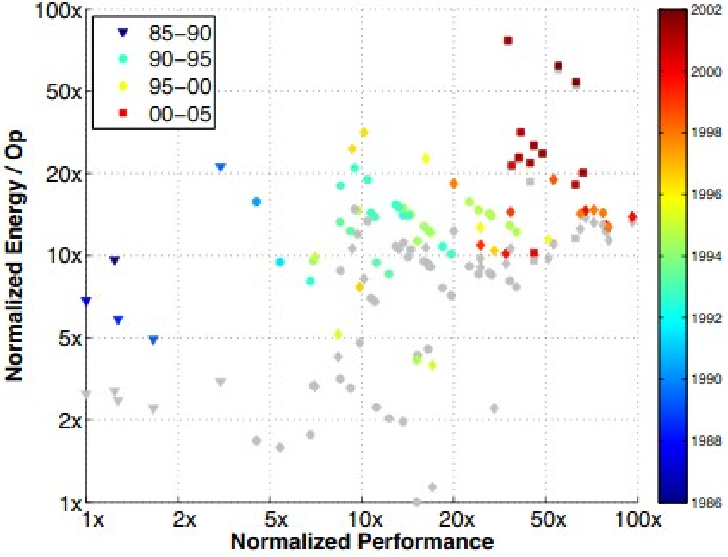

Figure 1.1.6: Instruction energy vs performance, with LLcache leakage added, with original points shown in grey for comparison.

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It gets worse . . .

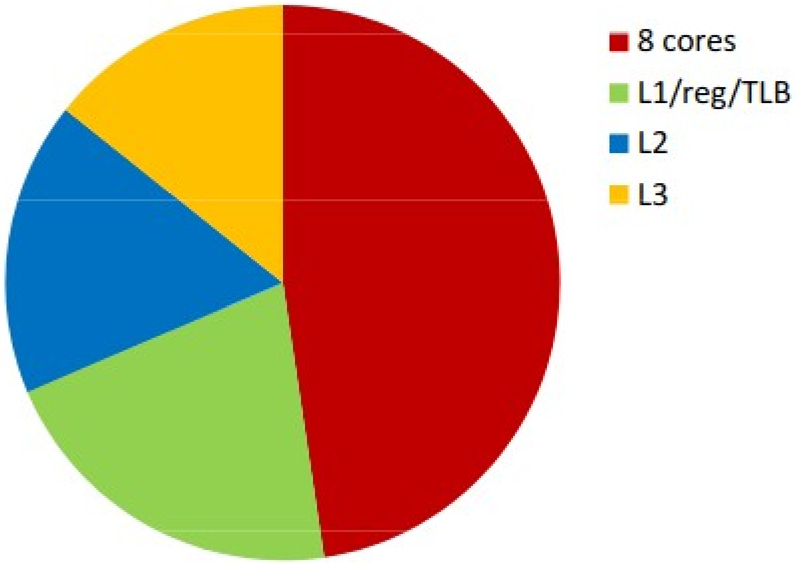

Figure 1.1.7: Power breakdown of an 8 core server chip.

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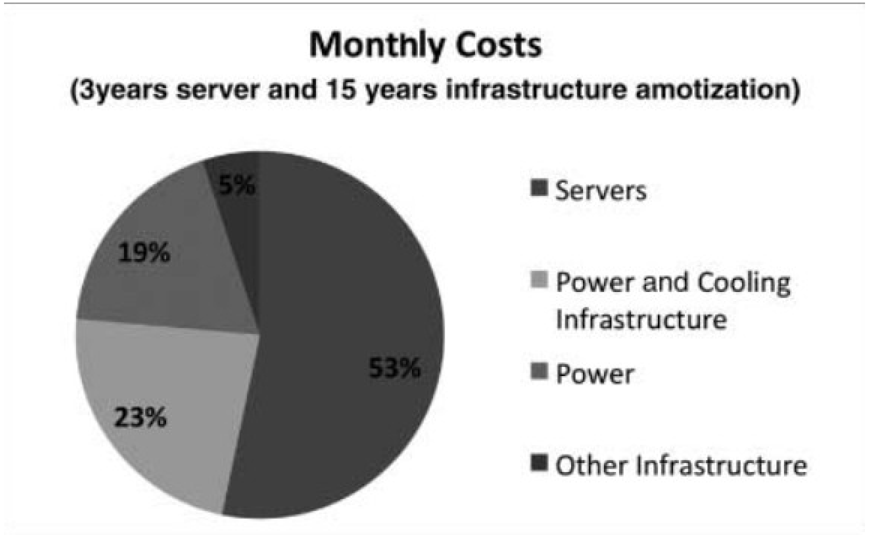
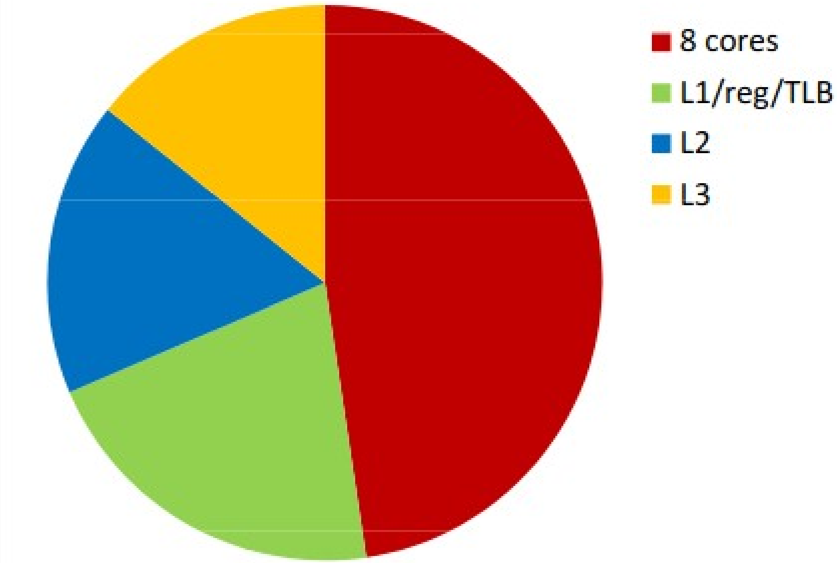


Berl, A., Gelenbe, E., Di Girolamo, M., Giuliani, G., De Meer, H., Dang, M. Q., & Pentikousis, K. (2010). Energy-efficient cloud computing. The computer journal, 53(7), 1045-1051.



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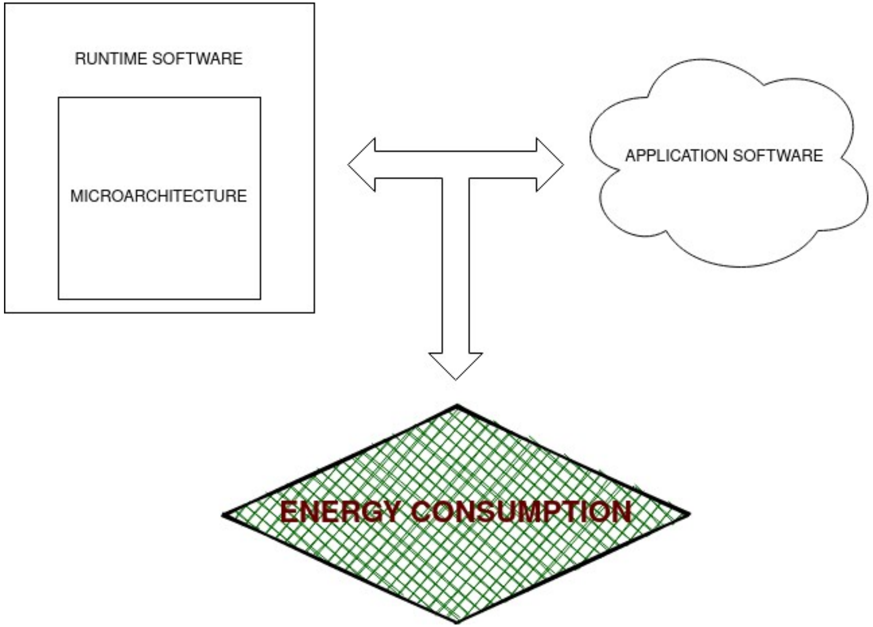

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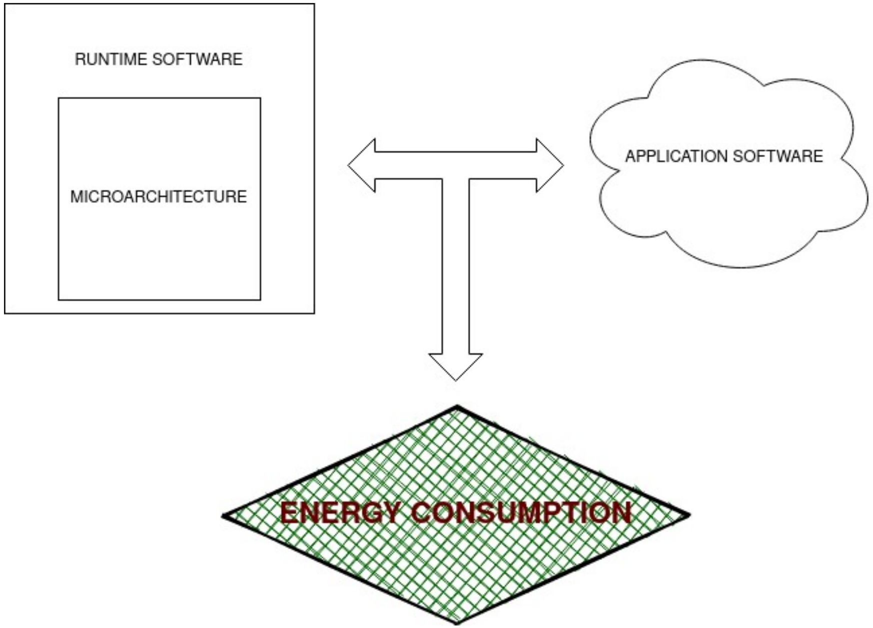

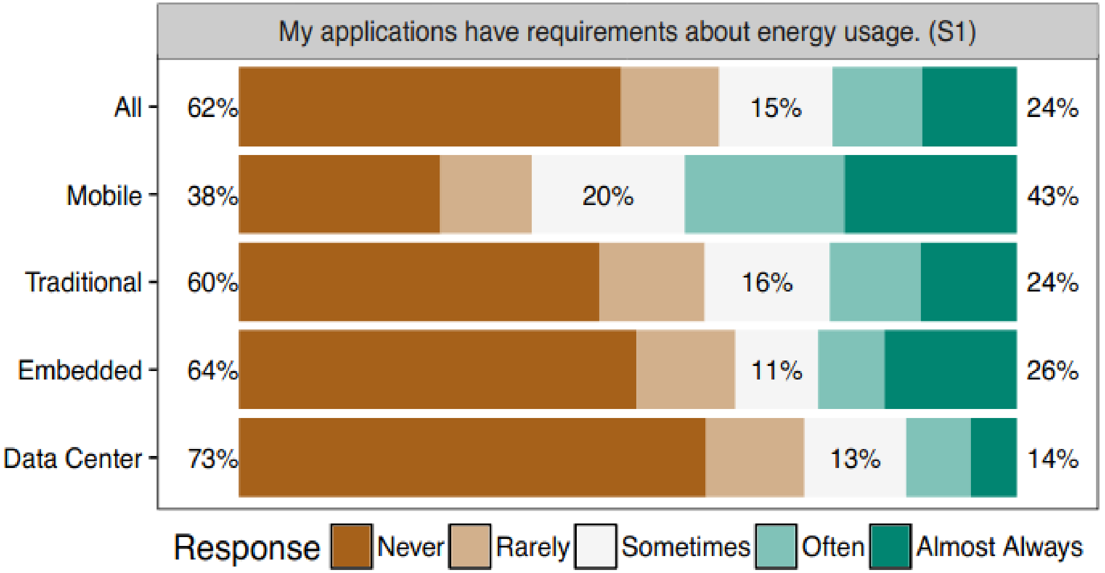

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Manotas, I., Bird, C., Zhang, R., Shepherd, D., Jaspan, C., Sadowski, C., ... & Clause, J. (2016, May). An empirical study of practitioners' perspectives on green software engineering. In 2016 IEEE/ACM 38th International Conference on Software Engineering (ICSE) (pp. 237-248). IEEE.

So where are we?

So where are we?

- It’s complicated...

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- It’s complicated…
  - ASIC’s (not flexible)
  - DVFS (microarch-constrained)
  - Accelerators (difficult to program)

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  - ASIC’s (not flexible)
  - DVFS (microarch-constrained)
  - Accelerators (difficult to program)
- ...but there are (kind of) new kids on the block!

So where are we?

RISC-V®

- It’s complicated…
  - ASIC’s (not flexible)
  - DVFS (microarch-constrained)
  - Accelerators (difficult to program)
- ...but there are (kind of) new kids on the block!

Deep Learning + RISC-V = ?

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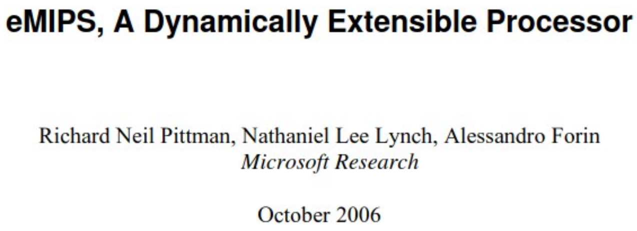
- Not much, on their own

Deep Learning + RISC-V = ?

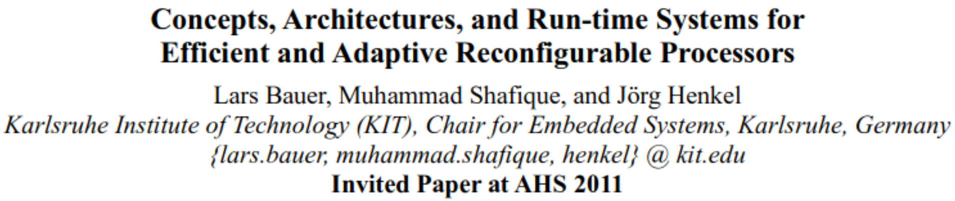
- Not much, on their own
- But what if we mixed **reconfigurable processors** in?



eMIPS, A Dynamically Extensible Processor

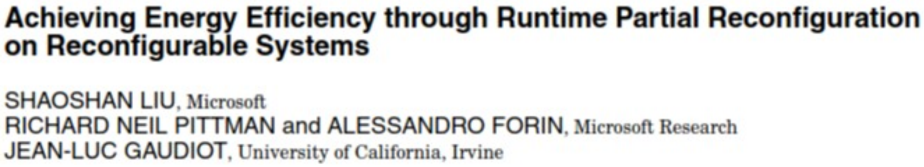
Richard Neil Pittman, Nathaniel Lee Lynch, Alessandro Forin
Microsoft Research

October 2006



Concepts, Architectures, and Run-time Systems for Efficient and Adaptive Reconfigurable Processors

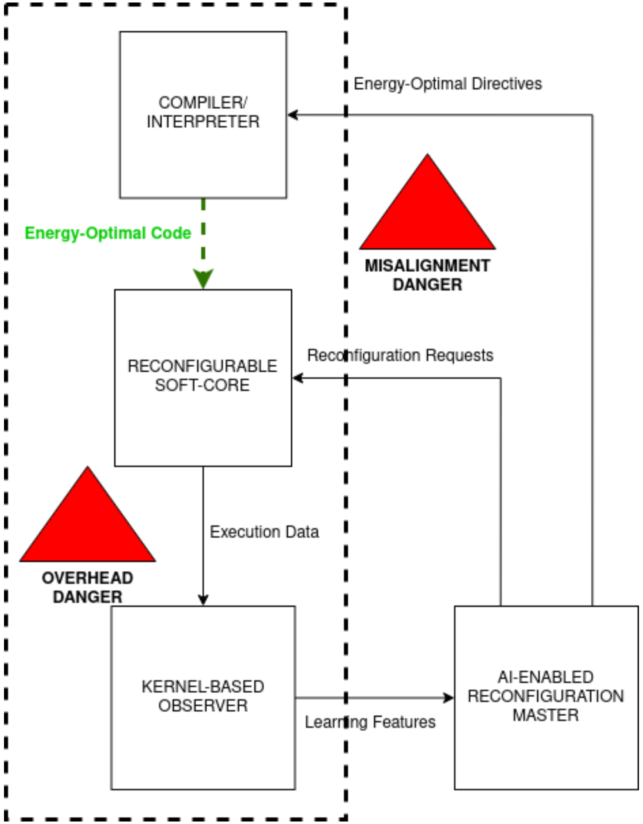
Lars Bauer, Muhammad Shafique, and Jörg Henkel
Karlsruhe Institute of Technology (KIT), Chair for Embedded Systems, Karlsruhe, Germany
{lars.bauer, muhammad.shafique, henkel} @ kit.edu
Invited Paper at AHS 2011



Achieving Energy Efficiency through Runtime Partial Reconfiguration on Reconfigurable Systems

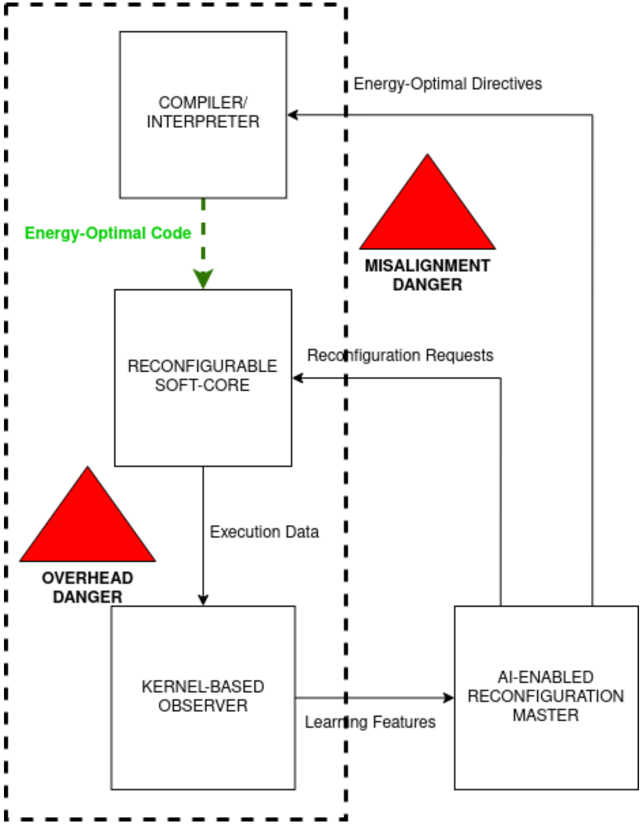
SHAOSHAN LIU, Microsoft
RICHARD NEIL PITTMAN and ALESSANDRO FORIN, Microsoft Research
JEAN-LUC GAUDIOT, University of California, Irvine

We should try this at home!

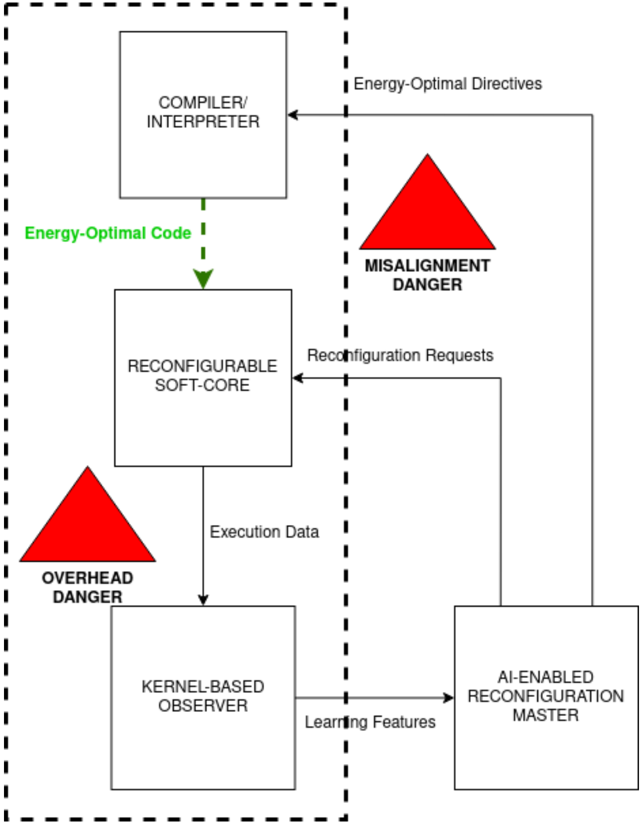


We should try this at home!

- RISC-V → reliable toolchain
- Deep Learning → complex energy models
- FPGA → dynamic adaptivity
- (Low-Power) Compiler Theory → robust background

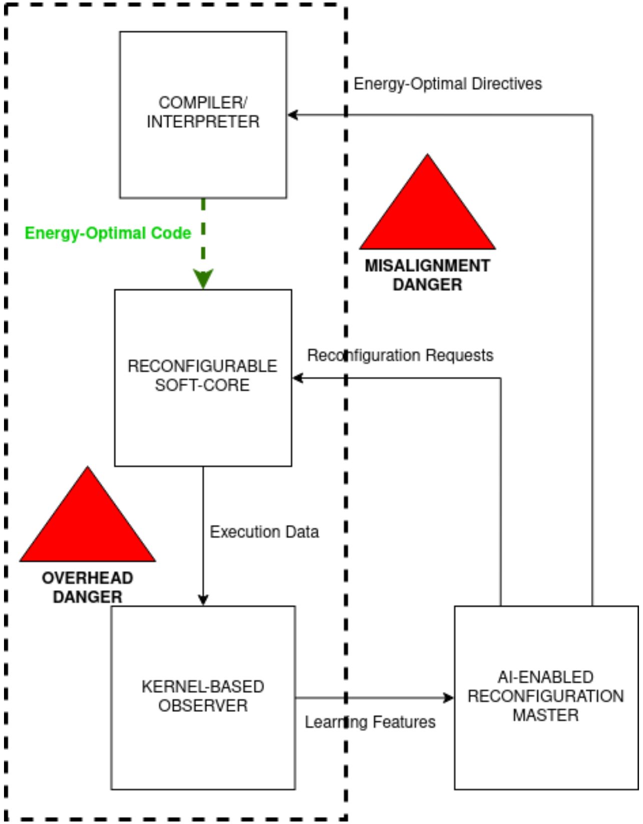


...shouldn’t we?


COMPILER/ INTERPRETER
Energy-Optimal Directives
Energy-Optimal Code
MISALIGNMENT DANGER
RECONFIGURABLE SOFT-CORE
Reconfiguration Requests
Execution Data
OVERHEAD DANGER
KERNEL-BASED OBSERVER
Learning Features
AI-ENABLED RECONFIGURATION MASTER

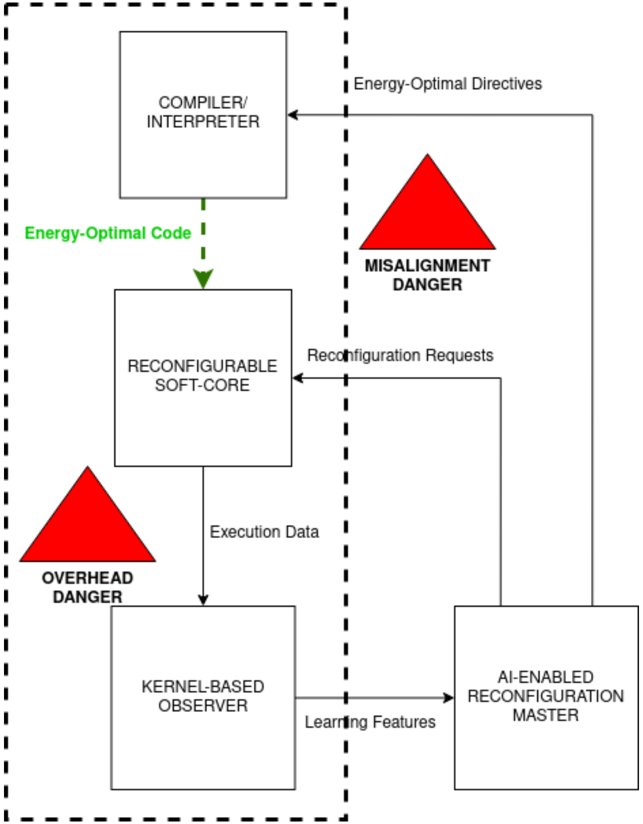
...shouldn’t we?

- *There **must** exist a reason why dynamically extensible processors haven’t conquered the industry yet*

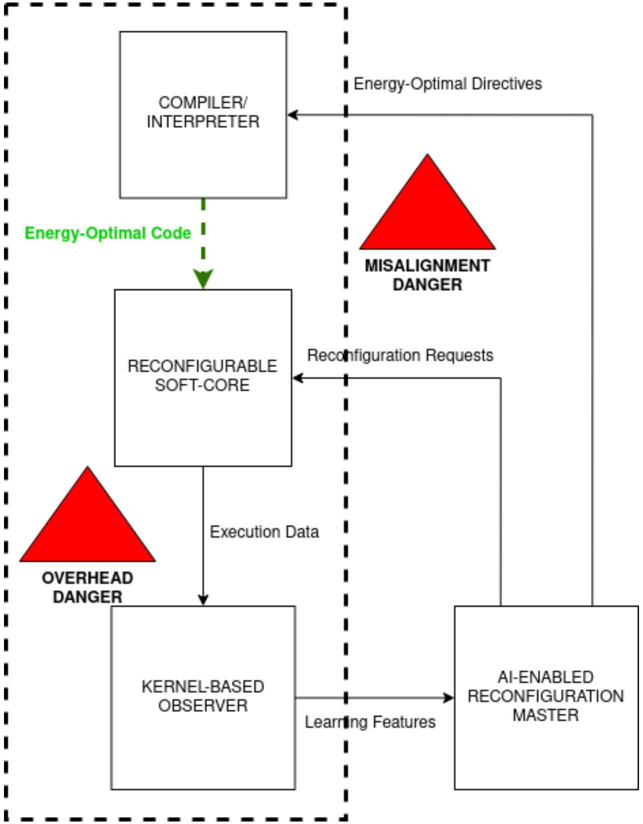


...shouldn’t we?

- *There* ***must*** *exist a reason why dynamically extensible processors haven’t conquered the industry yet*
- *Plus: the “system” imagined here has* ***a ton*** *of hidden red dangers (like the 2 shown)*



So could we go there?



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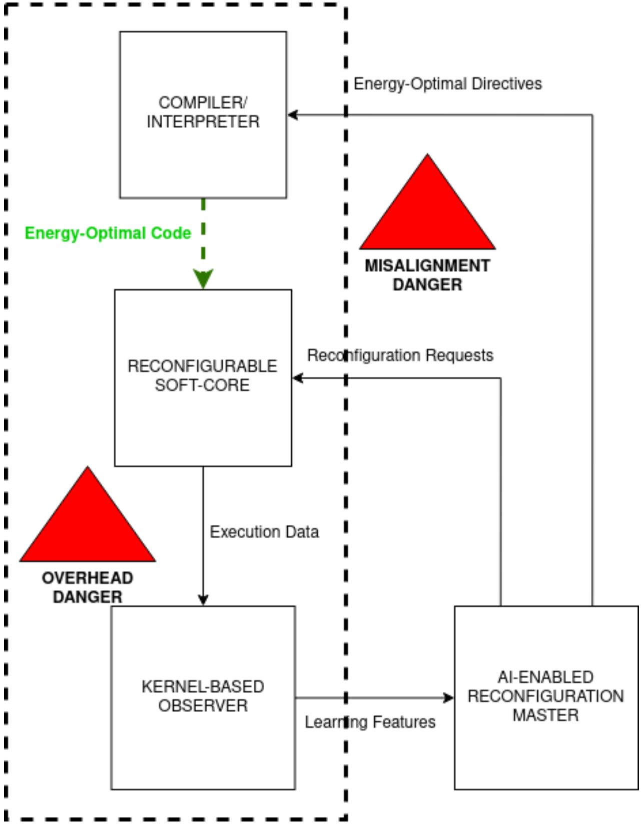

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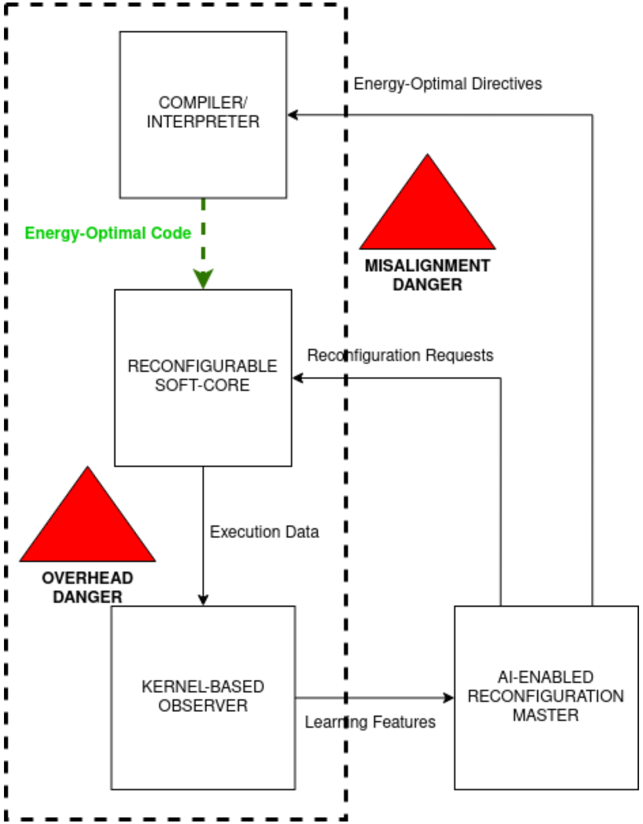
  - A grant proposal?



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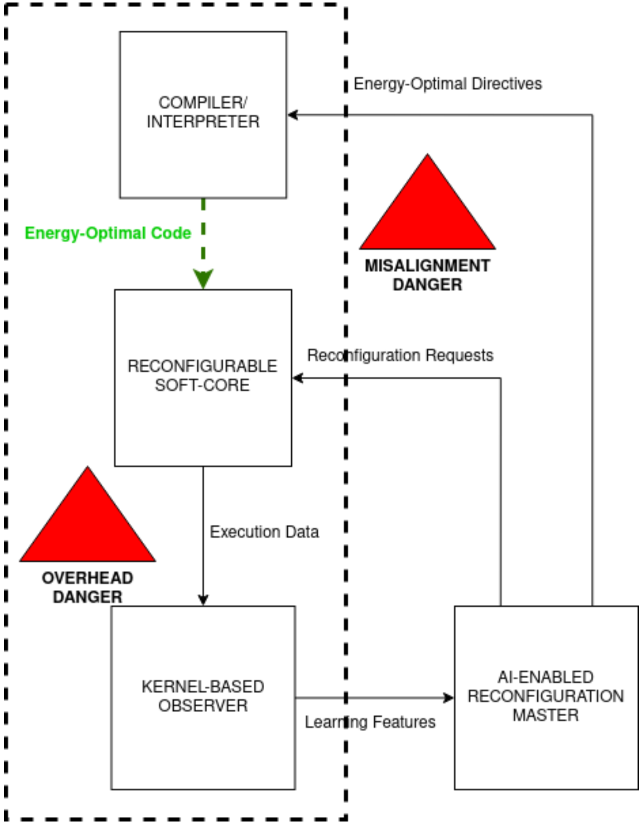
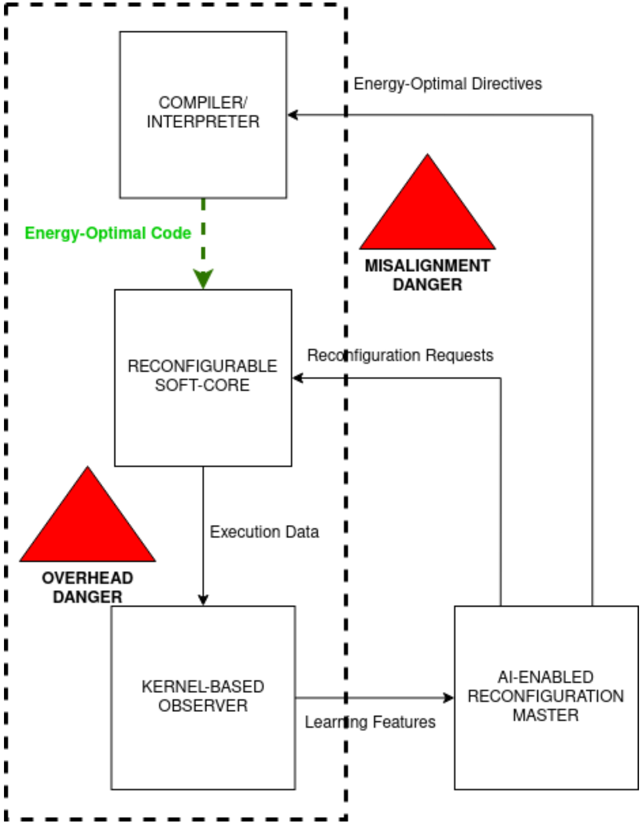
- What does this look like to you?
  - A grant proposal?
  - A crazy dream of an ignorant young man?



So could we go there?

- What does this look like to you?
  - A grant proposal?
  - A crazy dream of an ignorant young man?
  - *To Mr. Soudris:* a reason to fire me?



Let’s **talk!**

THANK YOU