Energy-Aware Computing Systems

Energiebewusste Rechensysteme

IX. Energy-Aware Programming

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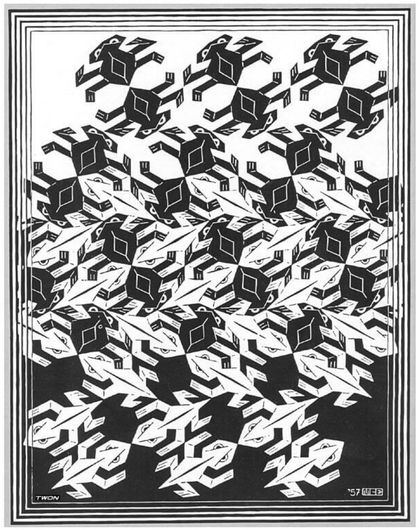
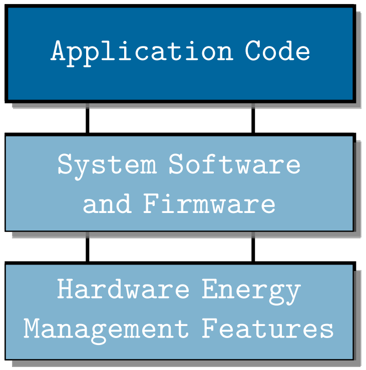
Agenda

Energy-Aware Programming

- **motivation**
  - knowledge transfer: development → execution phase
  - reduction of work to the necessary minimum
  - carry out the remaining work in the most efficient way
- **operational goals**
  - reduce guesswork by lower system levels (i.e., system software, firmware, and hardware)
  - interweave static aspects (→ ahead of run time) with dynamic aspects (→ at run time)



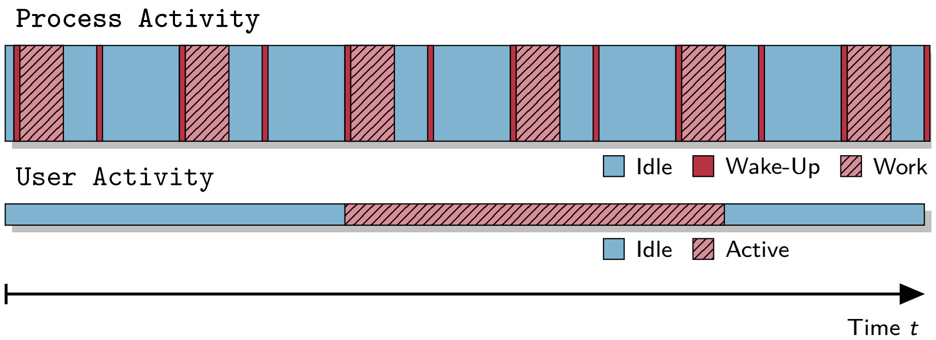
Cross-Layer Considerations



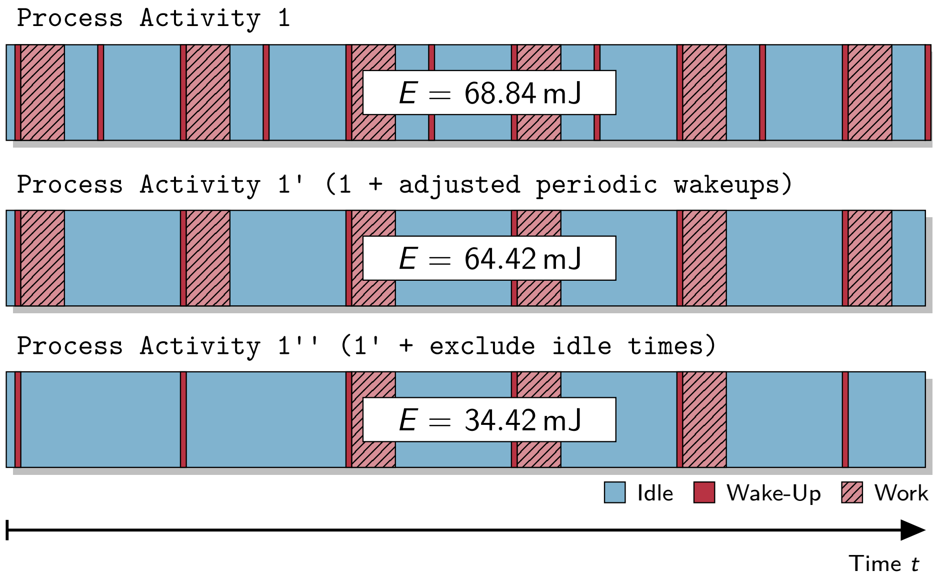
- compiler optimization (e.g., loop optimizations, aligned RAM access)
- tracing and profiling Tools (e.g., PowerTOP)
- energy management stack
- latency hiding, race/crawl to sleep
- dynamic voltage and frequency scaling (DVFS)
- sleep states (e.g., CPU C-states, device-specific power saving features)

Retrospective vs. Prospective: Analysis

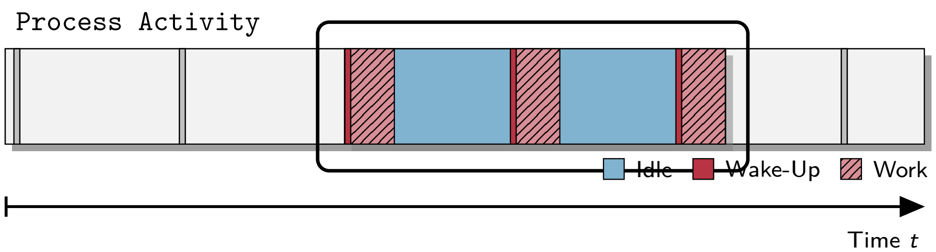
- statistics at process level (e.g., PowerTOP), unit of measurement is *wake-ups per second*
- wake-ups cause the CPU to return from C-state, subsequent activities (e.g., I/O) are likely to follow
- less wake-ups → lower energy demand

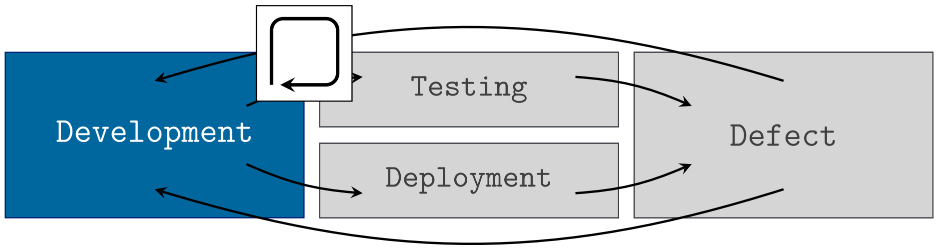


Retrospective vs. Prospective: Revisions and Impact



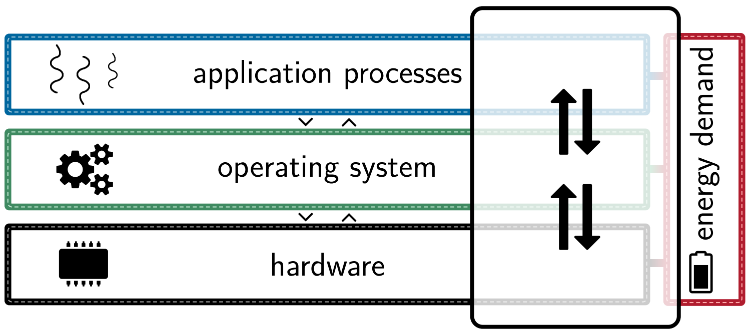
Retrospective vs. Prospective: Forward-Looking



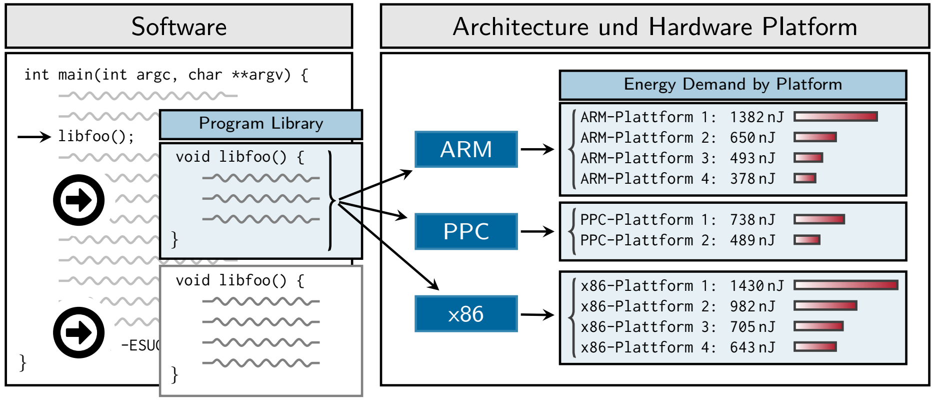


Energy-Aware Programming

- proactive energy-aware computing
  - cross-layer und cross-phase (positioning and momentum)
  - focus: single-chip computing systems and HPC
- holistic analysis and evaluation of software components with regard to their impact on the energy demand of the systems

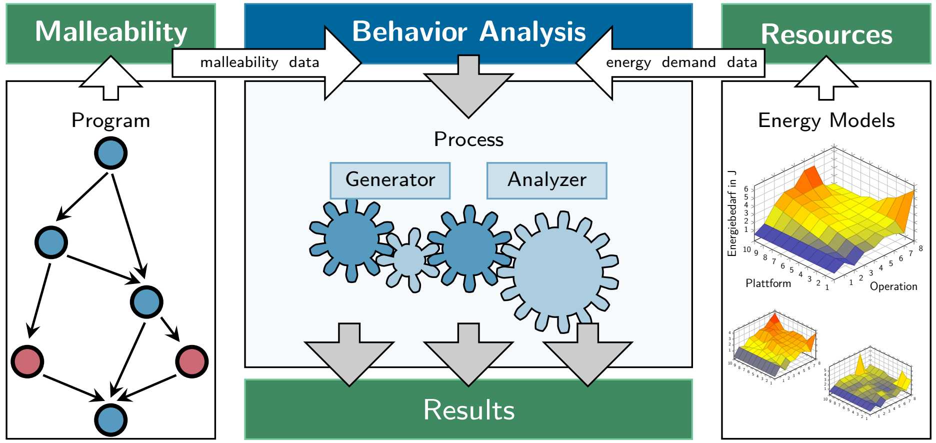


HEAL: Energy-Aware Programming



- making energy demand estimates at the function level available during development
- basis for energy-aware programming decisions

HEAL: Architecture and Implementation



- determine malleability by program analysis
- behavioral analysis with process execution and evaluation
- resource-demand analysis using energy models

HEAL: Program Example Fibonacci Sequence

Program:

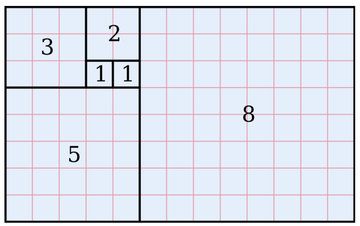
```
# modes: (l)ookup, static
#        (c)alculate, dynamic
#        (m)emoisation, dynamic

def main():
   mode = sys.argv[1]
   fnum = 42

   if mode == 'l':
      fib_lookup(fnum)
   elif mode == 'c':
      fib_calc(fnum)
   elif mode == 'm':
      fib_calc_mem(fnum)

if __name__ == "__main__":
   main()
```

HEAL:

1. path exploration (argv[1]: symbolic)
2. generate program with concrete input

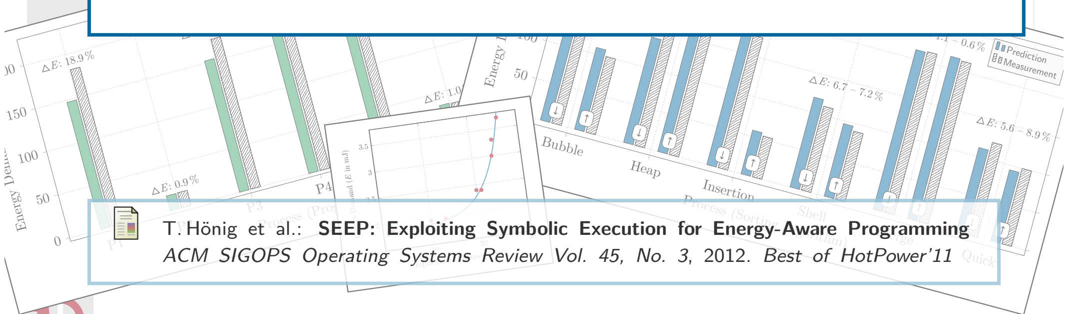
   z. B. argv[1]: 'c', fnum: 42
3. program execution and evaluation

   → energy demand estimate



HEAL: Results and Open Questions

- energy demand estimates deviate on average by less than 9.1 % compared to energy measurements
- the evaluation shows that the energy demand of functionally identical processes deviate up to 3.9 times



T. Hönig et al.: **SEEP: Exploiting Symbolic Execution for Energy-Aware Programming** *ACM SIGOPS Operating Systems Review Vol. 45, No. 3, 2012. Best of HotPower'11*

HEAL: Results and Open Questions

- ✔ comparison of (functionally identical) programs as to their different non-functional properties
- ✔ energy-demand analysis tightly integrated with the development process of software

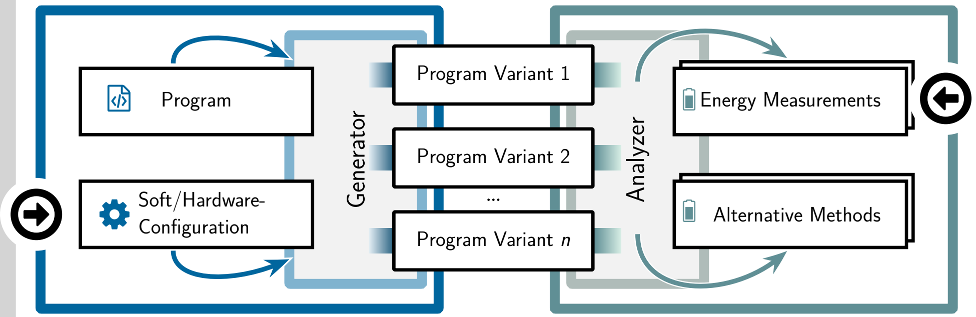
T. Hönig et al.: **SEEP: Exploiting Symbolic Execution for Energy-Aware Programming** *ACM SIGOPS Operating Systems Review Vol. 45, No. 3, 2012. Best of HotPower'11*

HEAL: Results and Open Questions

- ✖ missing and inaccurate energy models for hardware components are the rule
- ✖ unused potential to further reduce energy demand by pre-analysis of runtime energy-saving mechanisms

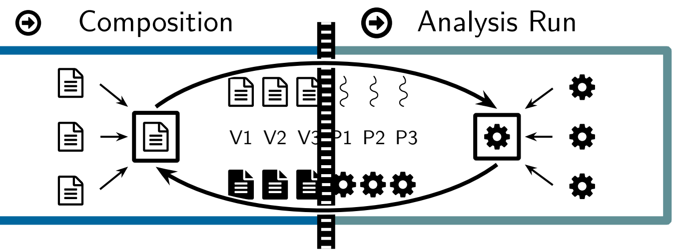
T. Hönig et al.: **SEEP: Exploiting Symbolic Execution for Energy-Aware Programming** *ACM SIGOPS Operating Systems Review Vol. 45, No. 3, 2012. Best of HotPower'11*

ROAM: Program Variant Generator and Analysis



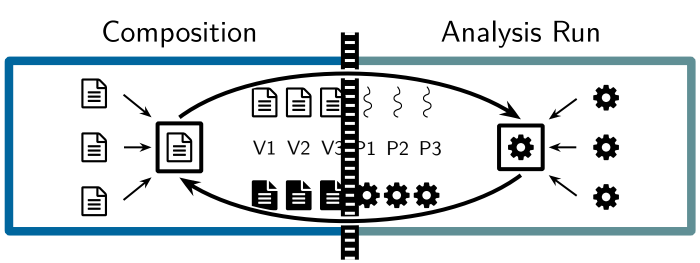
- generate program variants: programs with different software/hardware configurations
- energy measurements with a measuring circuit which is based on a current mirror for determining the energy demand

ROAM: Architecture and Implementation

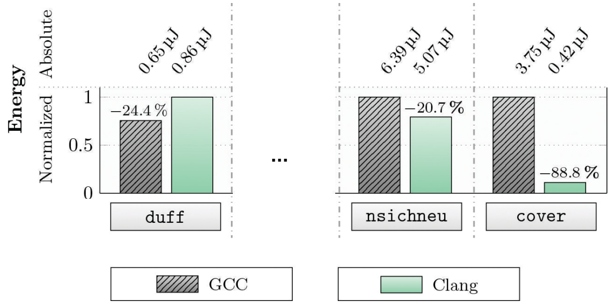


- composition: static preparation for testing
  - heterogeneous hardware settings (z. B. energy saving features)
  - different software settings (z. B. compiler)
- analysis run: dynamic evaluation
  - execution of program variants on different hardware platforms
  - determination of execution time and energy demand by measurement

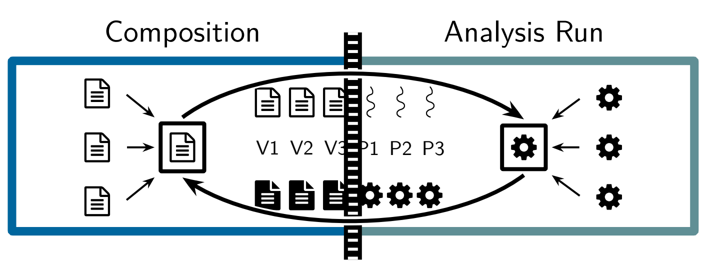
ROAM: Experiments and Results



First experiment[1]: comparison of interface-compatible compilers



ROAM: Experiments and Results



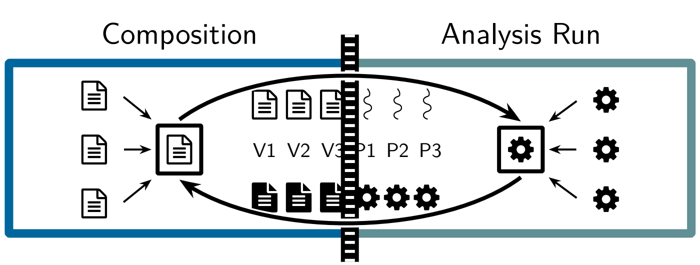
First experiment[1]: comparison of interface-compatible compilers

GCC vs. Clang
- in 80 % of the cases, GCC generates more energy-efficient program variants (up to a quarter lower energy demand)
- one program variant of Clang is approx. 10 x more energy-efficient than the corresponding variant of GCC

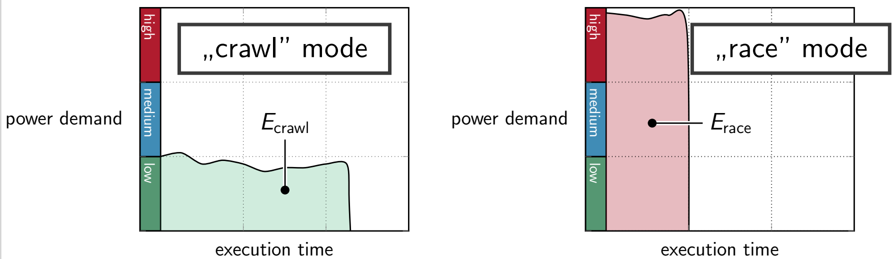
energy vs. time
- no causal relationship between process energy demand and execution time in 10 % of the program analyses

[1]Software: GNU GCC 4.8, LLVM Clang 3.4, Hardware: ARM Cortex-M0+ (Kinetis KL02)

ROAM: Experiments and Results

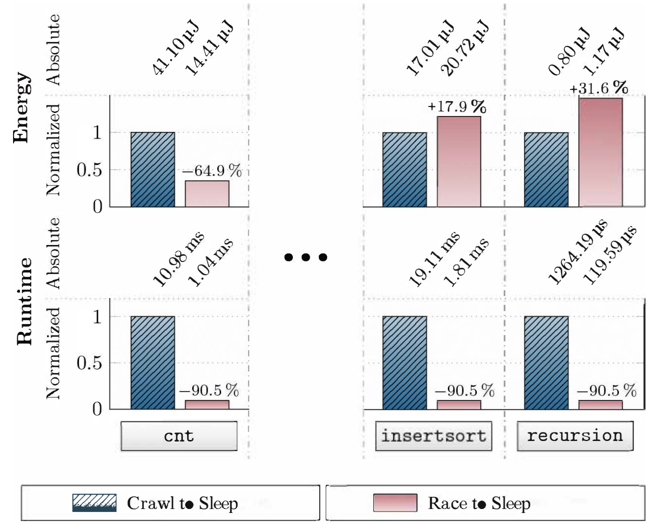


Second experiment[2]: scaling of operating voltage and clock frequency

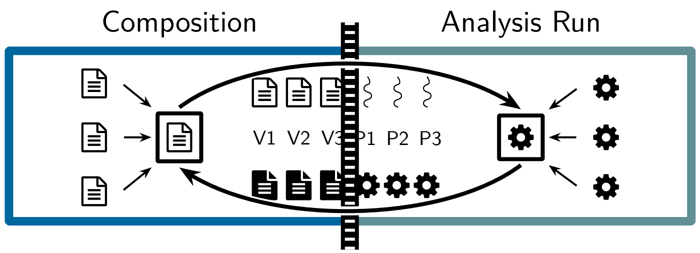


[2]Software: GNU GCC 4.8, Hardware: ARM Cortex-M0+ (Kinetis KL02, RUN/VLPR)

ROAM: Experiments and Results



ROAM: Experiments and Results



Second experiment[2]: scaling of operating voltage and clock frequency

- **race vs. craw**
  - „race" mode is commonly preferred to maximize idle time (→ exploit sleep modes)
  - expected increase in performance occurs in all test cases (i.e., shortening of the execution time)
- **energy vs. time**
  - however, <u>no</u> causal relationship between process energy demand and execution time in 20 % of the program analyses

[2]Software: GNU GCC 4.8, Hardware: ARM Cortex-M0+ (Kinetis KL02, RUN/VLPR)

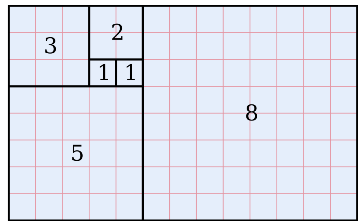
ROAM: Program Example Fibonacci Sequence (II)

Program:

```
# modes: (l)ookup, static
#        (c)alculate, dynamic
#        (m)emoisation, dynamic

def main():
    hwop = roam_fetch_hwops()
    mode = sys.argv[1]
    fnum = 42

    sw_hardware_mode(hwop);
    if mode == 'l':
        fib_lookup(fnum)
    elif mode == 'c':        ❮ race/crawl
        fib_calc(fnum)
    elif mode == 'm':        ❮ race
        fib_calc_mem(fnum)
    reset_hardware_mode();   ❮ crawl

if __name__ == "__main__":
    main()
```

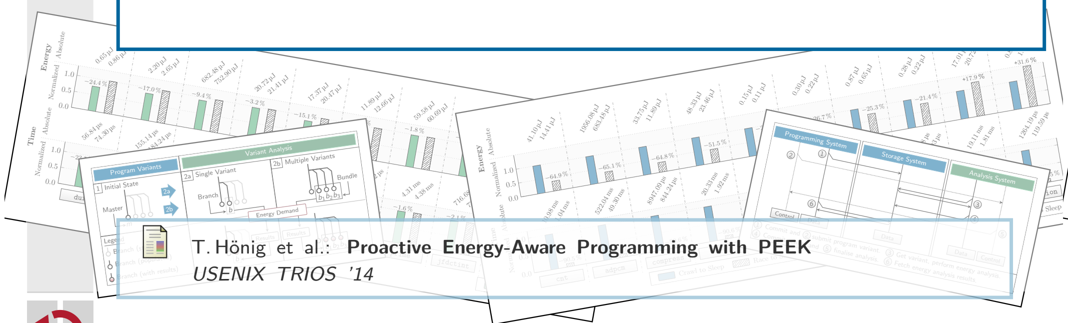
ROAM:

1. generate software and hardware settings to be used
2. generate program variants
3. process execution and evaluation
   - → energy demand measurements
   - → results evaluation



ROAM: Results

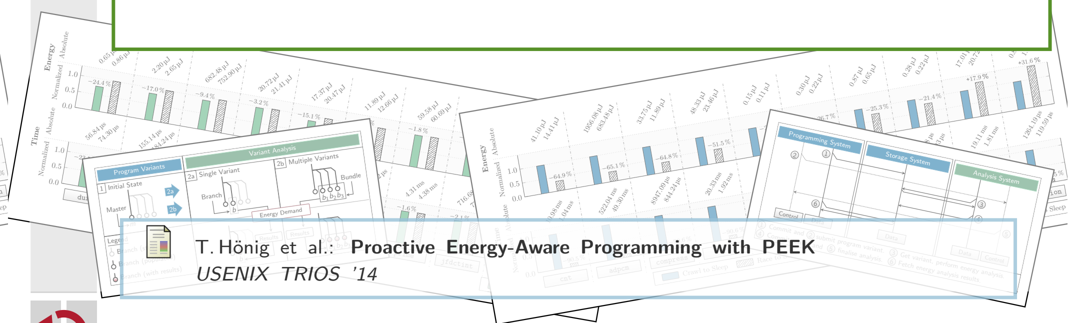
- configuration settings made by ROAM reduce hardware energy demand by between <u>18 % and 65 %</u>
- choosing the right compiler infrastructure can reduce the energy demand <u>by a factor of 10</u>



T. Hönig et al.: **Proactive Energy-Aware Programming with PEEK**
USENIX TRIOS '14

ROAM: Results

- ✔ pre-analysis generates necessary a priori knowledge for suitable hardware settings at process execution time
- ✔ energy measurement during analysis addresses unavailability of energy models



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Agenda

Preface and Terminology

System Activities and Energy Demand
- Cross-Layer Considerations
- Retrospective vs. Prospective

Energy-Aware Programming
- HEAL, ROAM
- Paper Discussion

Summary

Paper Discussion

- paper discussion
  - R. Pereira et al.
    Energy efficiency across programming languages: how do energy, time, and memory relate?
    Proceedings of the 10th ACM SIGPLAN International Conference on Software Language Engineering (SLE'17), 2017.

Subject Matter

- energy-aware programming connects **static** (ahead of run time) with **dynamic** (at run time) analysis
- use **cross-layer considerations** to reduce energy demand
- pinpoint relevant program code sections for **extended analysis** and manual labor
- reading list for Lecture 10:
  - X. Fan et al.
    Power provisioning for a warehouse-sized computer
    Proceedings of the 34th International Symposium on Computer architecture (ISCA'07), 2007.

Reference List I

[1] Hönig, T. ; Eibel, C. ; Kapitza, R. ; Schröder-Preikschat, W. :
SEEP: exploiting symbolic execution for energy-aware programming.
In: *Proceedings of the 2011 Workshop on Power-Aware Computing and Systems (HotPower '11)* ACM, 2011, S. 17–22. –
Best of HotPower 2011 Award.

[2] Hönig, T. ; Janker, H. ; Eibel, C. ; Mihelic, O. ; Kapitza, R. ; Schröder-Preikschat, W. :
Proactive Energy-Aware Programming with PEEK.
In: *Proceedings of the 2014 Conference on Timely Results in Operating Systems (TRIOS '14)* USENIX, 2014, S. 1–14