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Energy Efficiency Analysis of Compiler Optimizations on the SPEC CPU 2017 Benchmark Suite

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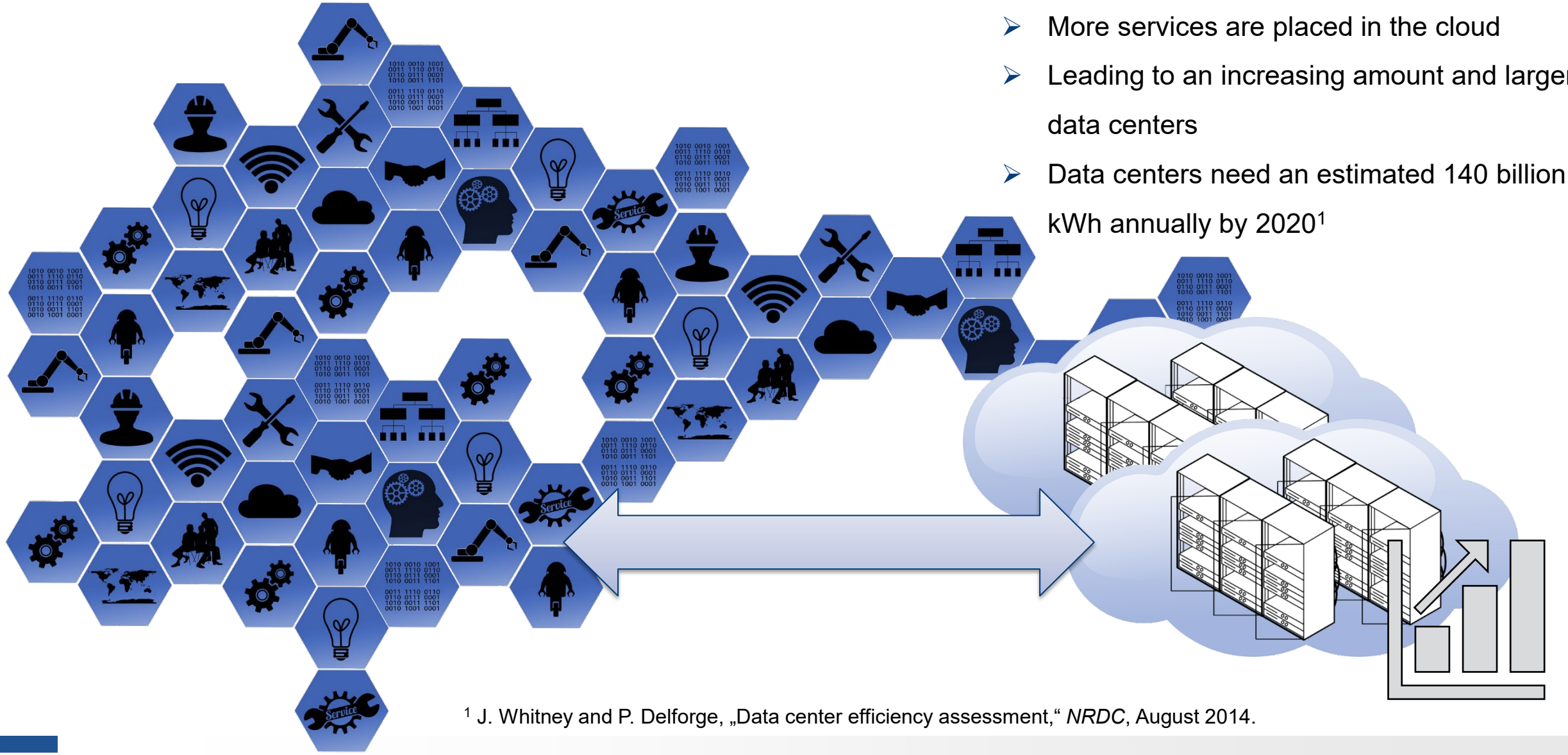
https://se.informatik.uni-wuerzburg.de/

Motivation

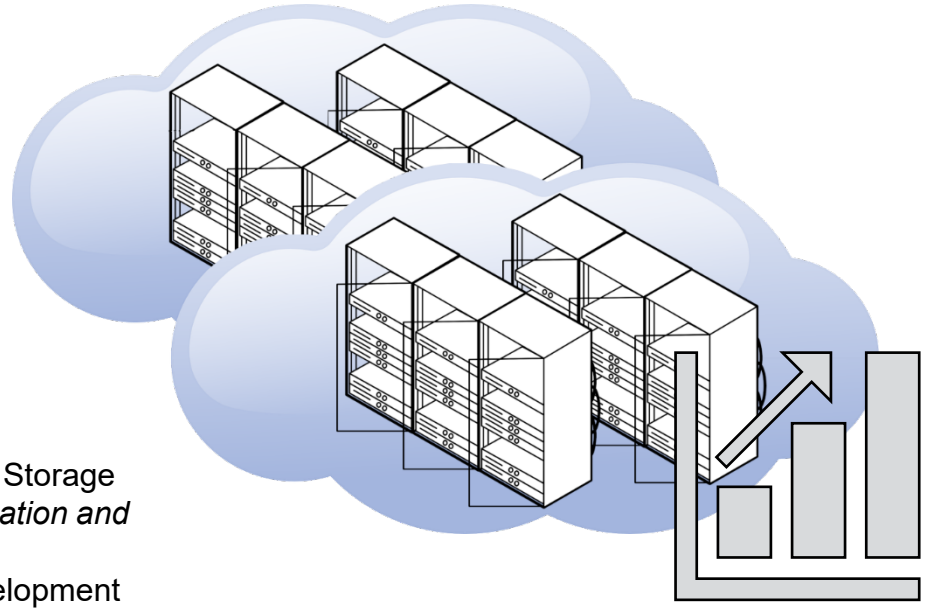
- More services are placed in the cloud
- Leading to an increasing amount and larger data centers
- Data centers need an estimated 140 billion kWh annually by 2020[1]



[1] J. Whitney and P. Delforge, „Data center efficiency assessment," *NRDC*, August 2014.

Motivation

- Cloud data centers can be made more efficient
  - Intelligently placing or consolidating services
  - Minimize resources through auto-scaling while satisfying performance demand
- Hardware can be made more efficient
  - Dynamic voltage and frequency scaling
  - Different C-States
- Software controls the hardware
- Running software has an influence on the energy efficiency of the complete system[2]
- Different, but functionally identical software can have a different energy efficiency while the performance does not change[3]

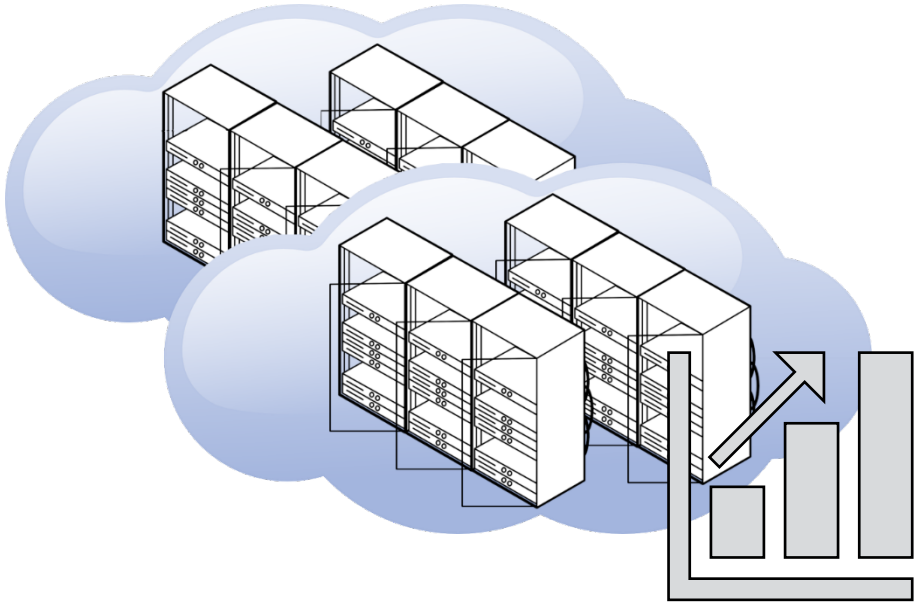


[2] Klaus-Dieter Lange. 2009. The Next Frontier for Power/Performance Benchmarking: Energy Eiciency of Storage Subsystems. In *Proceedings of the 2009 SPEC Benchmark Workshop on Computer Performance Evaluation and Benchmarking*.

[3] Eugenio Capra, Chiara Francalanci, and Sandra A. Slaughter. 2012. Is software green? Application development environments and energy efficiency in open source applications. Information and Software Technology 54, 1 (2012)

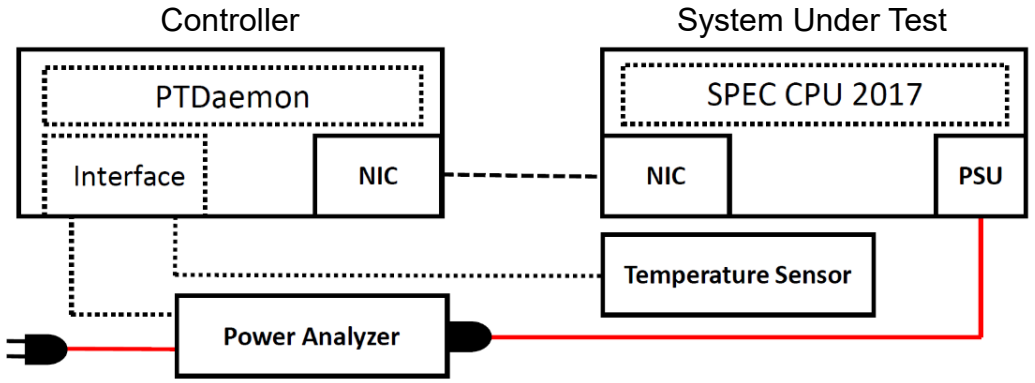
Contribution

- A first look at which factors make the software susceptible to compiler optimizations
  - Programming Language
  - Application domain
- Based on the SPEC CPU 2017 benchmark suite



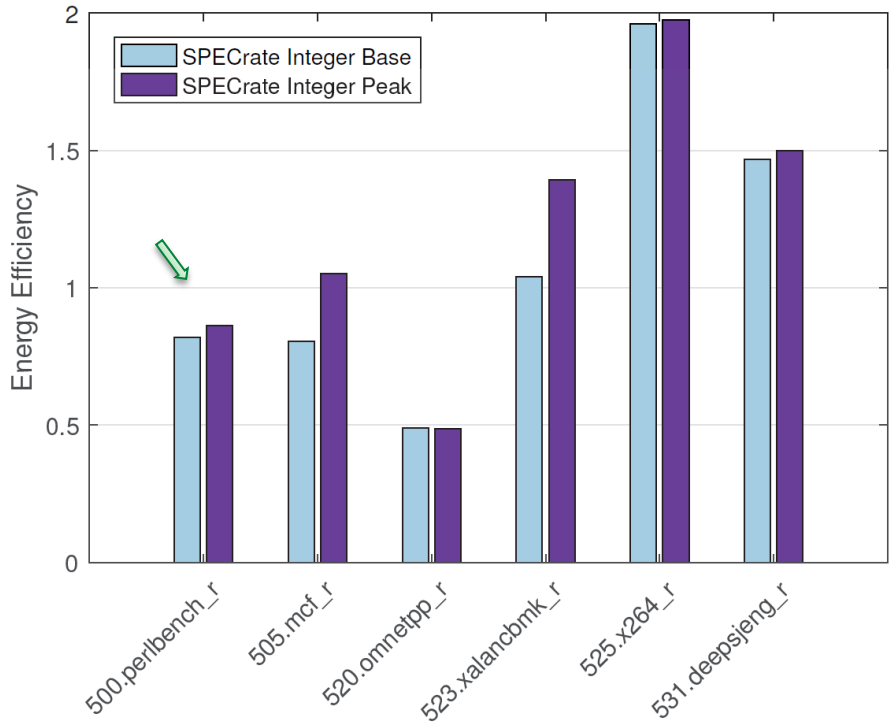
SPEC CPU 2017

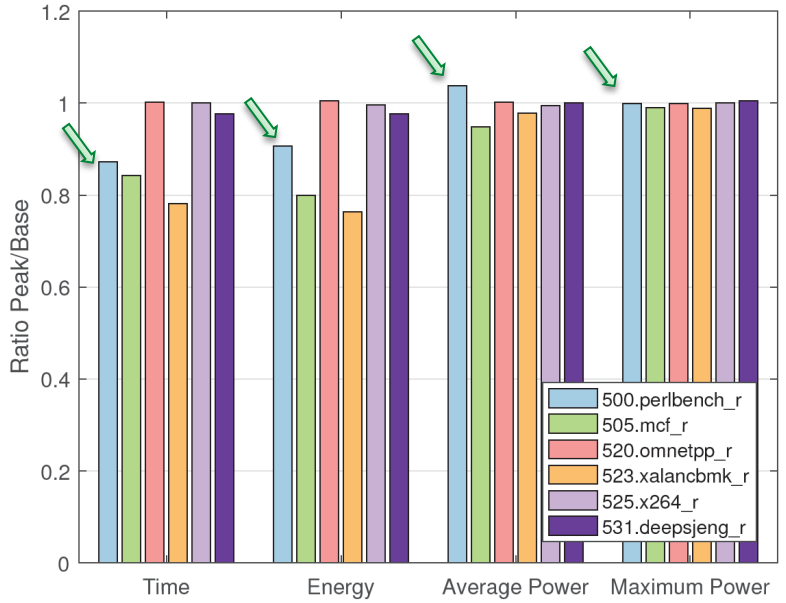
- SPEC CPU 2017 benchmark suite is compute-intensive
  - Different code and problem sizes
    - C, C++ and Fortran, covering multiple programming paradigms
    - 1000 to 1.5 million lines of code
  - Stressing CPU, memory and compiler
- Defined run and reporting rules for good repeatability
- 43 benchmarks organized in four suites
  - *SPECspeed Integer* and *Floating-Point*: Time required to process one unit of work
  - *SPECrate Integer* and *Floating-Point*: Work per unit of time (Throughput)
- Each of the four suites produces two metrics
  - *Base*: Each programming language, or combination, must use identical compiler settings
  - *Peak*: Each benchmark can use different compiler settings



Evaluation

- Relative comparison of *base* and *peak* values of the SPECrate Integer suite
- Benchmarks with identical compiler settings for *base* and *peak* runs are excluded
- Optimizing for performance can increase energy efficiency
- Example *500.perlbench_r*
  - 15% reduction in runtime
  - 5.5% better energy efficiency





Evaluation

- 23 benchmarks in SPECrate Integer and Floating-Point suites in total:
  - 7 excluded due to identical compiler settings
  - 16 benchmarks listed
  - 3 benchmarks implemented and counting towards two languages
- Can C-like languages be better optimized for energy efficiency?

Percentage of improved energy efficiency

Language	EE improved	Total	Percentage
C	8	8	100%
C++	6	7	85.7%
Fortran	1	4	25%

Evaluation

- H_0: C-like and functional languages are equally likely to show better energy efficiency
- H_0 must be rejected at the 5% level
- H_0 can not be rejected at the 1% level
- Possible reasons
  1. Compiler allows fewer optimizations for Fortran programs
  2. Functional programming provides an already energy-efficient programming style
  3. Results are outliers

Percentage of improved energy efficiency

Language	EE improved	Total	Percentage
C	8	8	100%
C++	6	7	85.7%
Fortran	1	4	25%

Fisher‘s exact test contingency table

	Energy Efficiency Improved		
Language	**Yes**	**No**	**Sum**
C-like	14	1	15
Functional	1	3	4
Sum	15	4	19

Evaluation

- 23 benchmarks in SPECrate Integer and Floating-Point suites in total:
  - 7 excluded due to identical compiler settings
  - 16 benchmarks listed
- Benchmarks were grouped into four application domains

Percentage of improved energy efficiency

App. Domain	EE improved	Total	Percentage
Language Transformation	2	2	100%
Modelling and Simulation	3	7	42.8%
Artifical Intelligence	1	1	100%
Others	6	6	100%

Conclusion

- Data centers consume large amounts of energy
- Use SPEC CPU 2017 benchmark suite to
  - Check if the compiler settings influence the benchmarks in terms of energy efficiency
  - See if the programming language is responsible for the improvement
  - See if the application domain is responsible for the improvement
- Comparison of programming languages show promising results that C-like languages can be easier optimized
- Application domain show nondistinctive results
- Further measurements on a broader set of software are necessary

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Thank You!

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