Who Ate My Battery?

Why Free and Open Source Systems Are Solving the Problem of Excessive Energy Consumption

Jeremy Bennett, Embecosm

Kerstin Eder, Computer Science, University of Bristol

Why?

Ericsson T65

- released 2001
- Li-Ion 720 mAh
- standby 300 h
- talk time 11 h
- includes talk/standby prediction

Sony Ericsson Xperia X10 mini

- released 2010
- Li-polymer 930 mAh
- standby up to 285 h (3G) / 360 h (2G)
- talk time up to 4 h (2G) / 3.5 h (3G)

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

All Computers Large and Small

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Some Mathematics

$$Energy = Power \times Time$$

or

$$Power = Energy \div Time$$

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Hardware Engineers are Very Good
Dynamic Voltage and Frequency Scaling

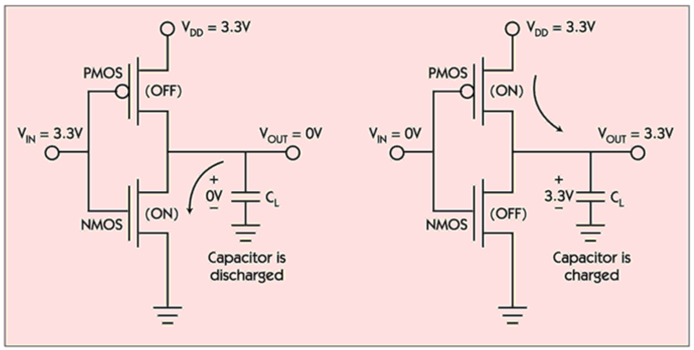
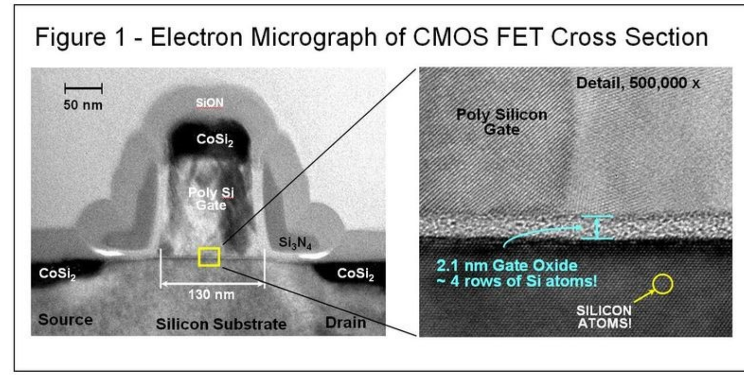


Fig. 1 Dynamic power in a CMOS inverter.



Dynamic energy loss

$$P \propto V^2 R.f \text{ and } f \propto V$$
$$P \propto f^3$$
$$E = P.t \text{ and } t = 1/f$$
$$E \propto f^2 \text{ and } E \propto V^2$$

Static energy loss

$$P = V^2 R \text{ and } f \propto V$$
$$P \propto f^2$$
$$E = P.t \text{ and } t = 1/f$$
$$E \propto f \text{ and } E \propto V$$

Turn off circuits that are not being used: clock gating

Atmel AVR ATxmega256 @3.0V and 2MHz:	Idle current 290µA
Atmel AVR ATxmega256 @1.8V and 32kHz:	Idle current 4µA

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Energy Transparency from Hardware to Software

Kerstin Eder
Design Automation and Verification, Microelectronics

University of Bristol
Department of Computer Science
The Royal Academy of Engineering
XMOS
EMBECOSM
University of Bristol

Free Mobile Apps “Drain Battery Faster”

BBC Mobile | News | Sport | Weather | iPlayer | TV

NEWS TECHNOLOGY

Home | World | UK | England | N. Ireland | Scotland | Wales | Business | Politics | Health | Education | Sci/Enviro

19 March 2012 Last updated at 17:34

1.7K Share

Free mobile apps 'drain battery faster'

Free mobile apps which use third-party services to display advertising consume considerably more battery life, a new study suggests.

Like many games, Angry Birds has a free version supported by targeted advertising

Researchers used a special tool to monitor energy use by several apps on Android and Windows Mobile handsets.

Findings suggested that in one case 75% of an app's energy consumption was spent on powering advertisements.

Report author Abhinav Pathak said app makers must take energy optimisation more seriously.

Related Stories

Hot mobile trends for

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Energy-Aware System Design

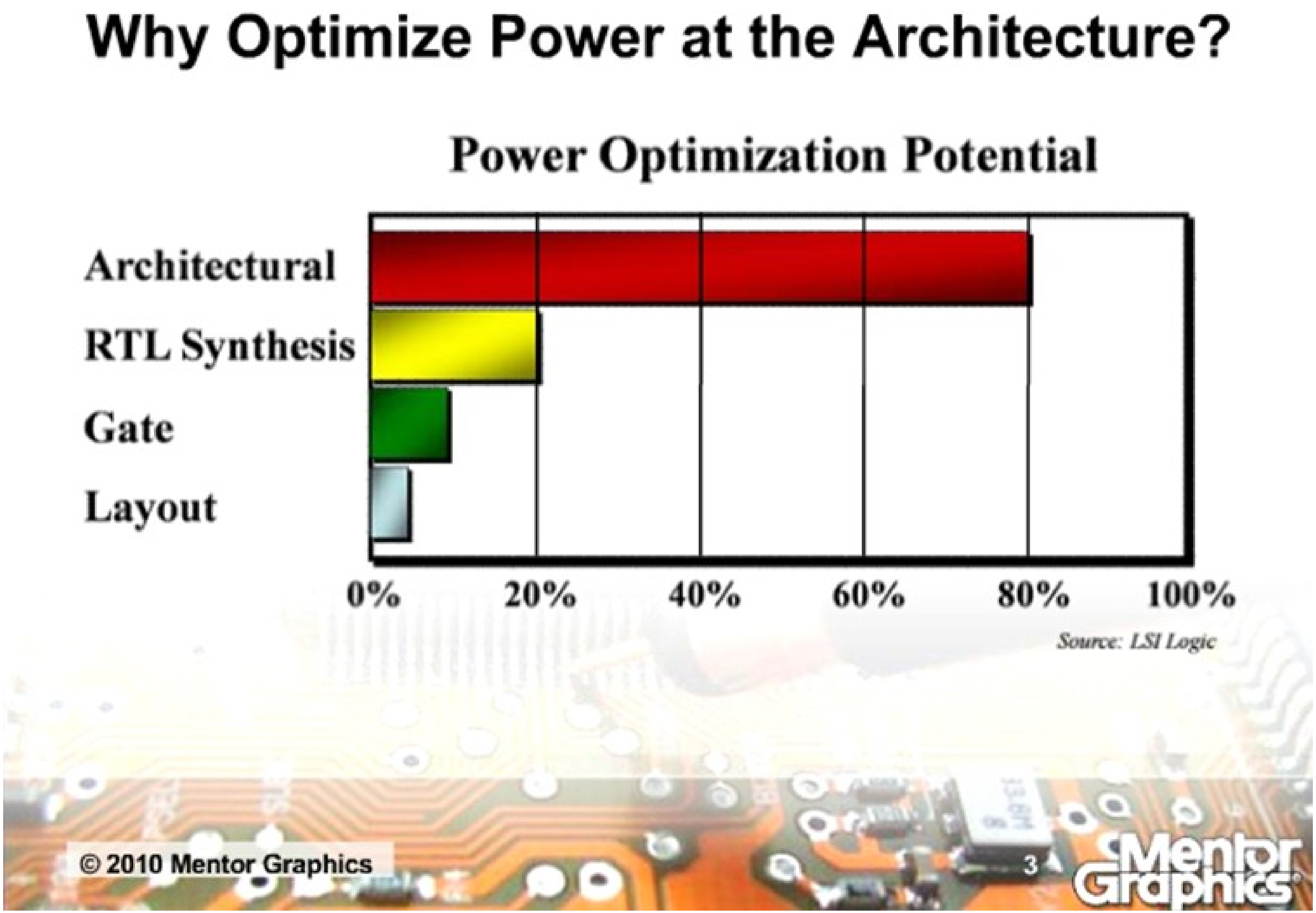
- Power management largely in domain of Hardware Design
  - Considerations to minimize/optimize
    - Dynamic (switching) and static (leakage) power
    - Energy consumption
  - On-chip power management
    - DVFS
    - Modes: on, standby, suspend, sleep, off
- Where can the greatest savings be made?

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Greater Savings at Higher Levels



Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

LOW POWER

Lack of software support marks the low power scorecard at DAC

One of the panels at the Design Automation Conference (DAC), which took place in California in early June, set out to get an idea of how well the industry is doing at delivering lower-power systems.

It is becoming clear, *writes Chris Edwards*, that the system level is currently the missing link.

Processes can deliver some gains – and Globalfoundries' Andrew Brotman was able to outline some of the features that the foundry has put into its recently launched low-power high-k, metal gate (HKMG) process.

FinFETs should bring power down as those processes become available, although they are not the only options. But if the software keeps cores active for no good reason, the lower switching power per bit processed won't deliver a realised saving.

In his keynote speech Gadi Singer, vice-president IAG and general manager of the SoC enabling group at Intel Corporation, said that with limited software support, dedicated low-power circuitry could save maybe 20% in a typical multimedia-oriented core.

Make the software controlling it better at controlling the power states and that difference could be three to five times.

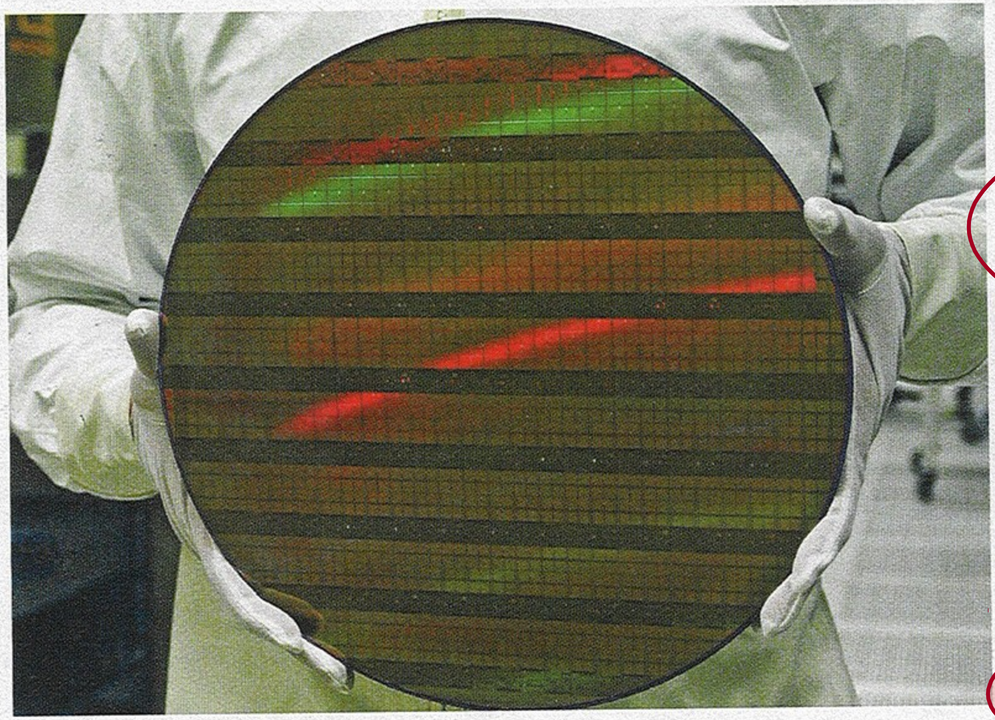
During an afternoon panel discussion Ambrose Low, director of design engineering at Broadcom said: "We have hundreds of knobs in the hardware to turn power down.

"The question is whether we can take the actual use-cases into consideration and optimise the software to power the logic circuits down. We still have a long way to go."

Ruggero Castagnetti of LSI argued that the desire to do more in software will grow.

"As we see power limits and targets becoming unachievable, customers will be willing to go to that extra step. There is a challenge that needs to be addressed and we have to do more on the systems side," Castagnetti said.

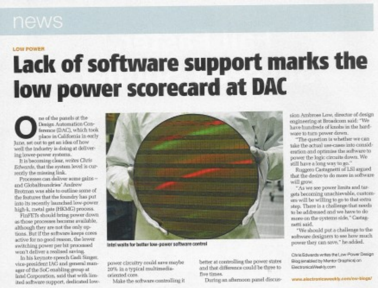
"We should put a challenge to the software designers to see how much power they can save," he added.



Intel waits for better low-power software control

Chris Edwards writes the Low-Power Design Blog (enabled by Mentor Graphics) on ElectronicsWeekly.com

www.electronicsweekly.com/ew-blogs/


news

LOW POWER

Lack of software support marks the low power scorecard at DAC

Wasted Potential

Huge advances have been made in power-efficient hardware.

Various software-controllable energy-saving features available, such as DVFS, power modes.

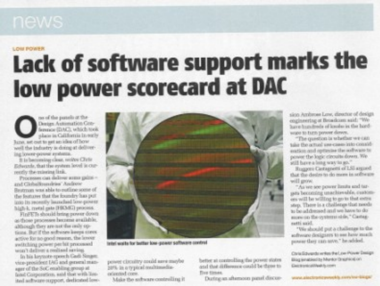
BUT – potential energy savings are wasted by

- software that does not exploit energy-saving features of hardware;
- poor dynamic management of tasks and resources.

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL


news

Lack of software support marks the low power scorecard at DAC

The Focus is on Software

- Software controls the behaviour of the hardware
  - Algorithms and Data Flow
  - Compiler (optimizations)
    - traditional SW design goals:
      - performance, performance, performance
- Software engineers often **"blissfully unaware"**
  - Implications of algorithm/code/data on power/energy?
  - Power/Energy considerations
    - at best, secondary design goals
  - BUT the biggest savings can be gained from optimizations at the higher levels of abstraction in the system stack – this includes Algorithms, Data and SW

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Aligning SW Design Decisions with Energy-Efficiency Design Goal

Key steps*:

- *"Choose the **best algorithm** for the problem at hand and make sure it **fits well with** the computational **hardware**. Failure to do this can lead to costs far exceeding the benefit of more localized power optimizations.*
- *Minimize **memory size** and expensive **memory accesses** through algorithm transformations, efficient mapping of data into memory, and optimal use of memory bandwidth, registers and cache.*
- *Optimize the **performance** of the application, making **maximum use of available parallelism.***
- *Take advantage of **hardware support for power management**.*
- *Finally, select instructions, sequence them, and order operations in a way that **minimizes switching** in the CPU and datapath."*

* Kaushik Roy and Mark C. Johnson. **1997**. "Software design for low power". In *Low power design in deep submicron electronics*, Wolfgang Nebel and Jean Mermet (Eds.). Kluwer Nato Advanced Science Institutes Series, Vol. 337. Kluwer Academic Publishers, Norwell, MA, USA, pp 433-460.

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

6.3. SOFTWARE DESIGN FOR LOW POWER

KAUSHIK ROY AND MARK C. JOHNSON
School of Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana, U.S.A.

1. Introduction

It is tempting to suppose that only hardware dissipates power, not software. However, that would be analogous to postulating that only automobiles burn gasoline, not people. In microprocessor, micro-controller, and digital signal processor based systems, it is software that directs much of the activity of the hardware. Consequently, the software can have a substantial impact on the power dissipation of a system. Until recently, there were no efficient and accurate methods to estimate the overall effect of a software design on power dissipation. Without a power estimator there was no way to reliably optimize software to minimize power. Since 1993, a few researchers have begun to crack this problem. In this chapter, you will learn

Energy Transparency

Information on energy usage is available for programs:

- (ideally) without executing them, and
- at all levels from machine code to high-level application code.

EMBECOSM®

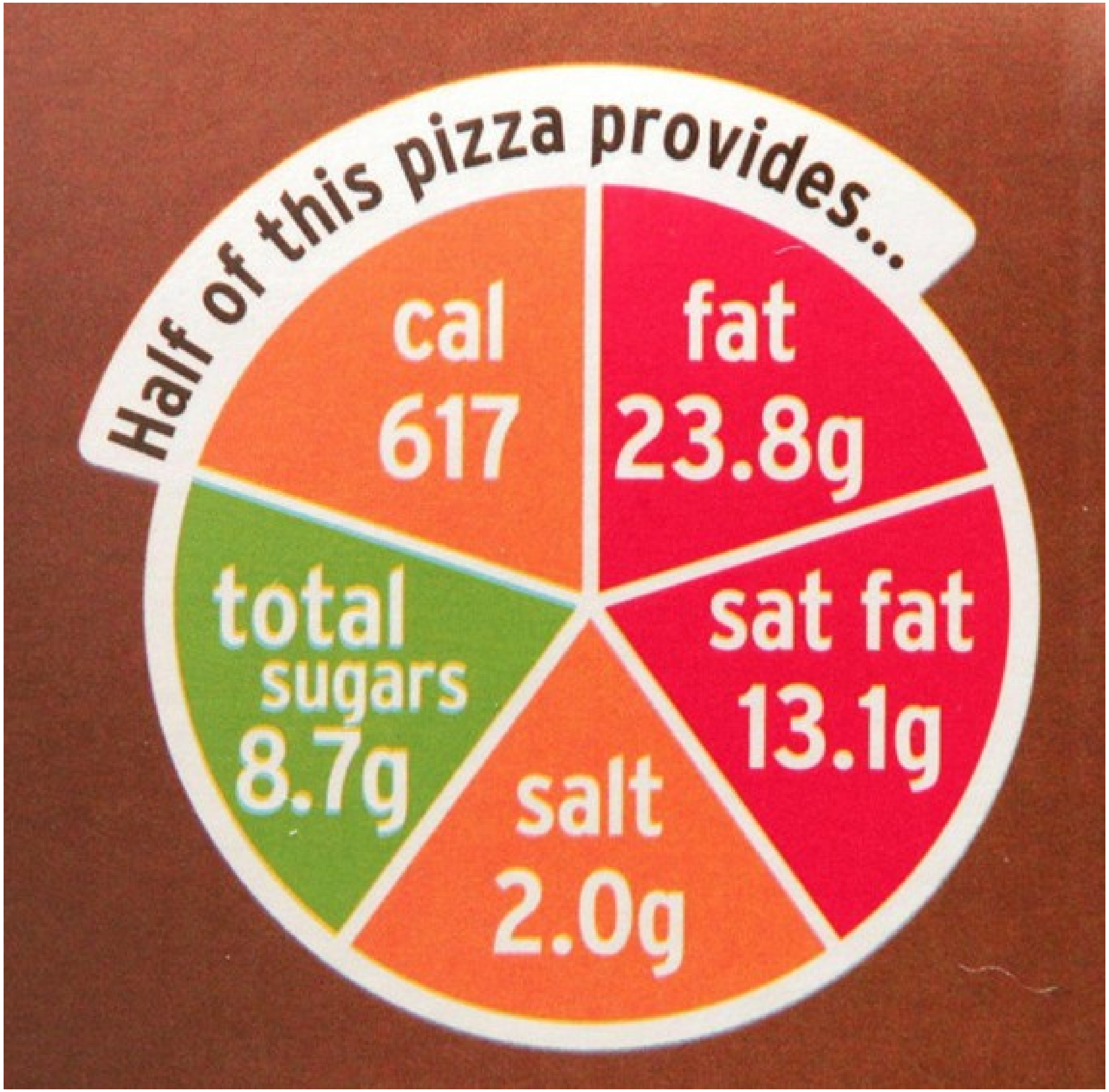
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Transparency

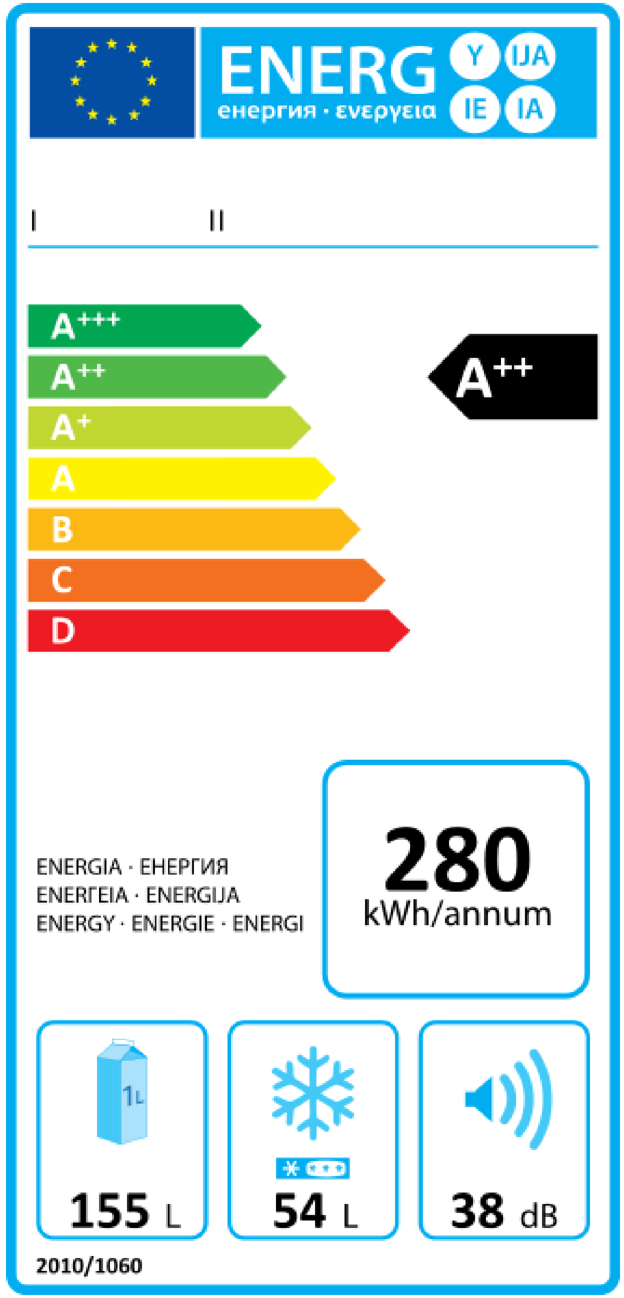
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Transparency



Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Transparency

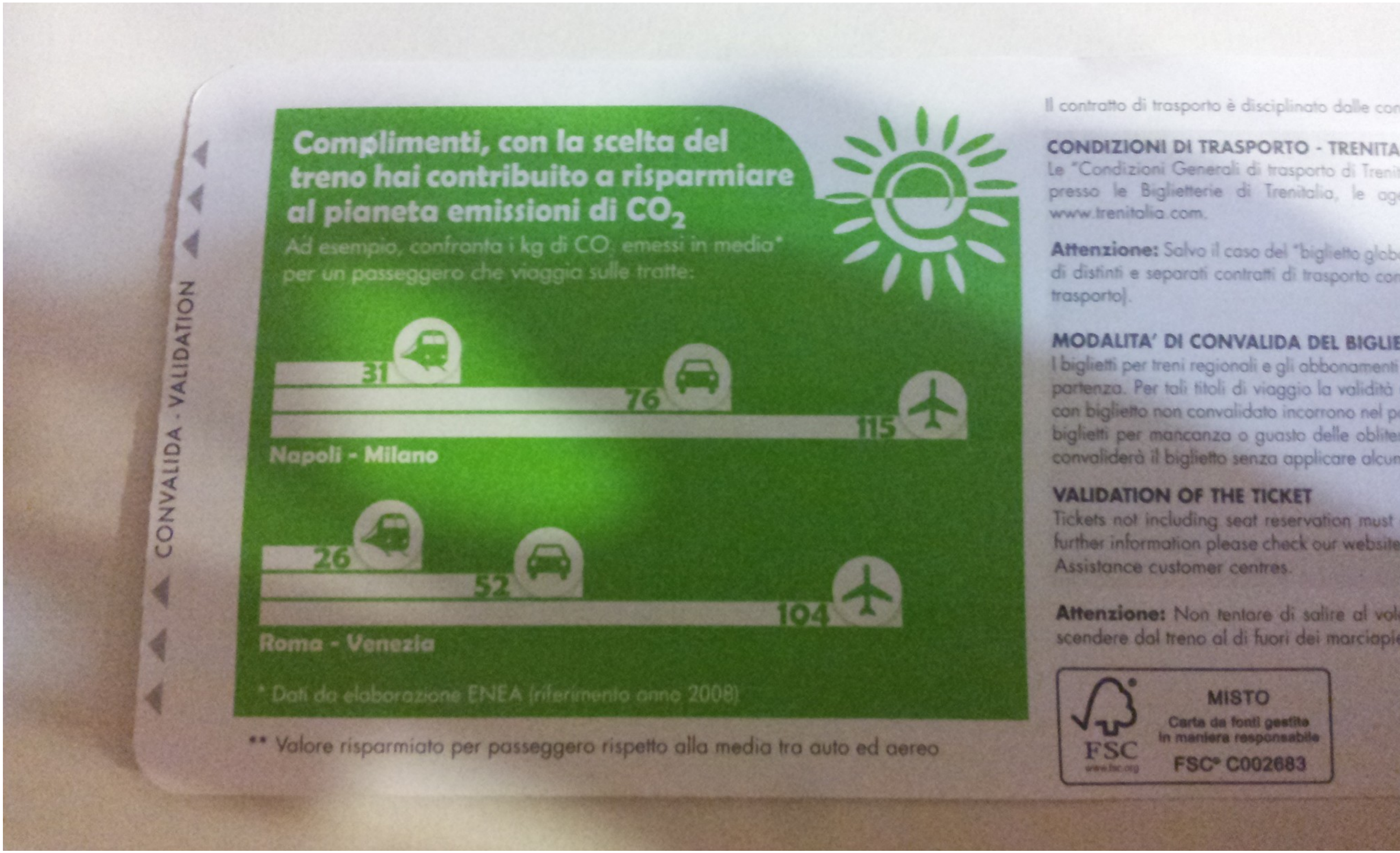


EMBECOSM®

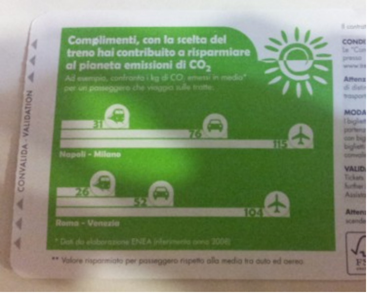
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Transparency



Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license



Why Energy Transparency?

Energy transparency enables a deeper understanding of how algorithms and coding impact on the energy consumption of a computation when executed on hardware.

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

The EACOF

A simple Energy-Aware Computing Framework

https://github.com/eacof/eacof

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Comparing Sorting Algorithms

- Sorting of integers in [0,255]

		Data Type											
		uint8_t			uint16_t			uint32_t			uint64_t		
Algorithm	Num Elements	Total Time (s)	Total Energy (J)	Average Power (W)	Total Time (s)	Total Energy (J)	Average Power (W)	Total Time (s)	Total Energy (J)	Average Power (W)	Total Time (s)	Total Energy (J)	Average Power (W)
Bubble Sort	50,000	5.53	66.66	12.03	5.39	65.29	12.09	5.66	69.05	12.19	5.78	71.83	12.41
Insertion Sort	200,000	7.98	■102.18	12.75	7.98	■103.00	12.85	7.46	■98.81	13.21	7.54	■105.03	13.89
Quicksort	2,000,000	5.51	61.73	11.20	5.53	61.90	11.19	5.52	61.60	11.15	5.51	62.90	★11.42
Merge Sort	60,000,000	•6.06	•72.33	11.93	6.07	72.46	11.93	6.12	75.65	12.36	•5.93	•76.98	★12.98
qsort	100,000,000	•5.84	•72.39	12.37	6.15	76.90	12.48	6.79	86.29	12.69	•5.69	•73.25	12.86
Counting Sort	200,000,000	0.23	♦2.92	12.75	0.24	♦3.16	13.23	0.25	♦3.58	14.15	0.35	♦5.12	14.44

- ■ Insertion Sort: 32 bit version more optimized
- ♦ Counting Sort:
  75% more energy for 64 bit compared to 8 bit values
- • Sorting 64 bit values takes less time than sorting 8 bit values, but consumed more energy
- ★ Average power variations between algorithms

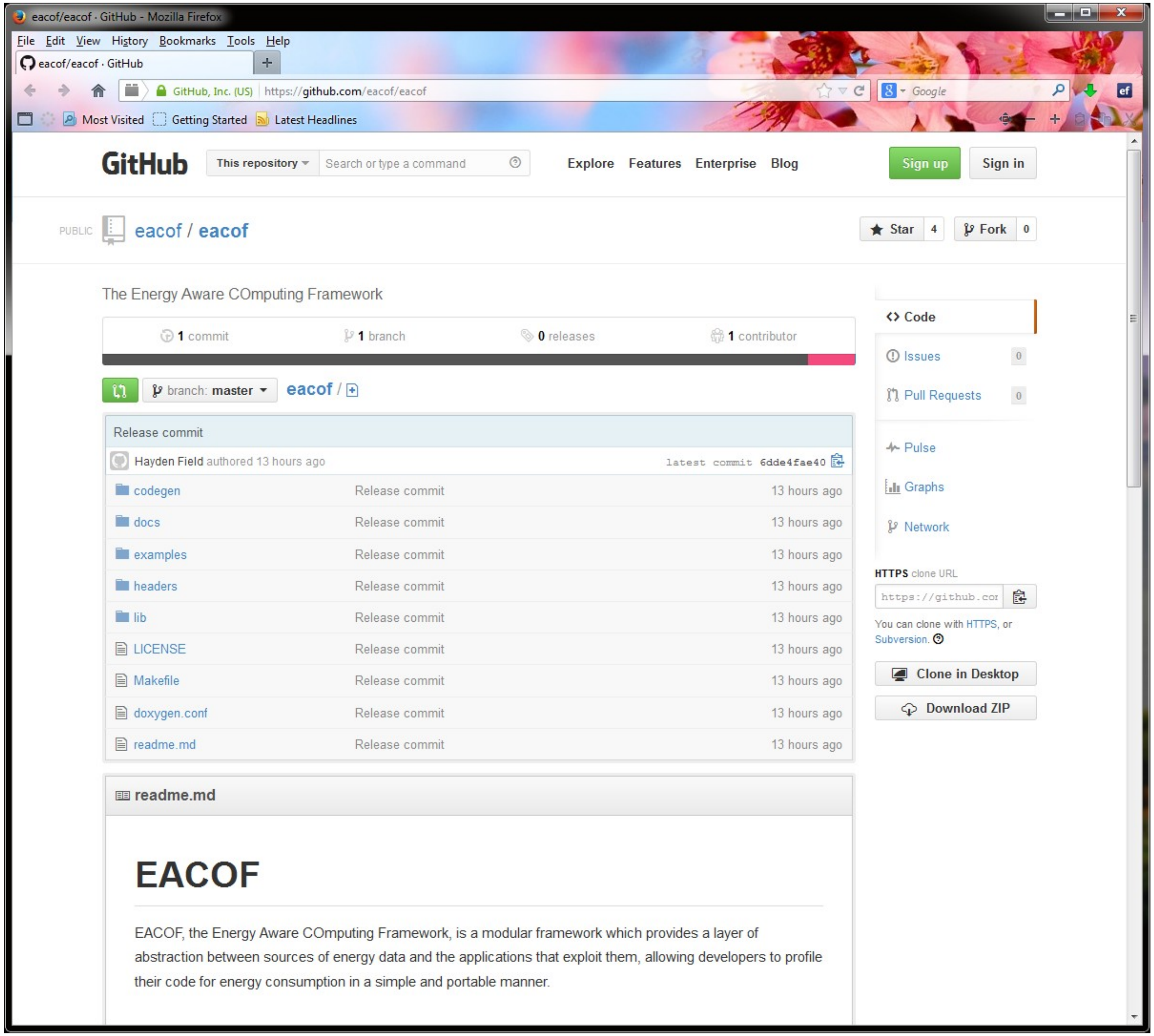
Hayden Field, Glen Anderson, Kerstin Eder, EACOF: A Framework for Providing Energy Transparency to enable Energy-Aware Software Development. *29th ACM Symposium On Applied Computing*. pp. tbc–tbc. March 2014.

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

First EACOF release



https://github.com/eacof/eacof

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

ENTRA

Whole-Systems
Energy Transparency

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

The ENTRA Project

- Whole Systems ENergy TRAnsparency
  - 1.10.2012 - 30.9.2015
  - EC FP7 FET MINECC:

    “Software models and programming methodologies supporting the strive for the energetic limit (e.g. energy cost awareness or exploiting the trade-off between energy and performance/precision).”

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Energy Modelling

Data to enable

Energy Transparency

Energy Modeling

Energy Cost *(E)* of a program *(P)*:

$$E_P = \sum_i (B_i \times N_i) + \sum_{i,j} (O_{i,j} \times N_{i,j}) + \sum_k E_k$$

Instruction Base Cost, B_i, of each instruction i

Circuit State Overhead, $O_{i,j}$, for each instruction pair

Other Instruction Effects (stalls, cache misses, etc)

V. Tiwari, S. Malik and A. Wolfe. "Instruction Level Power Analysis and Optimization of Software", Journal of VLSI Signal Processing Systems, 13, pp 223-238, 1996.

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

XCore Energy Modelling

Energy Cost *(E)* of a multi-threaded program *(P)*:

$$E_{\mathrm{p}} = P_{\mathrm{base}} N_{\mathrm{idle}} T_{\mathrm{clk}} + \sum_{t=1}^{N_t} \sum_{i \in \mathrm{ISA}} \left(\left(M_t P_i O + P_{\mathrm{base}} \right) N_{i,t} T_{\mathrm{clk}} \right)$$

Idle base power and duration

Concurrency cost, instruction cost, generalised overhead, base power and duration

- Use of execution statistics rather than execution trace.
- Fast running model with an average error margin of less than 7%

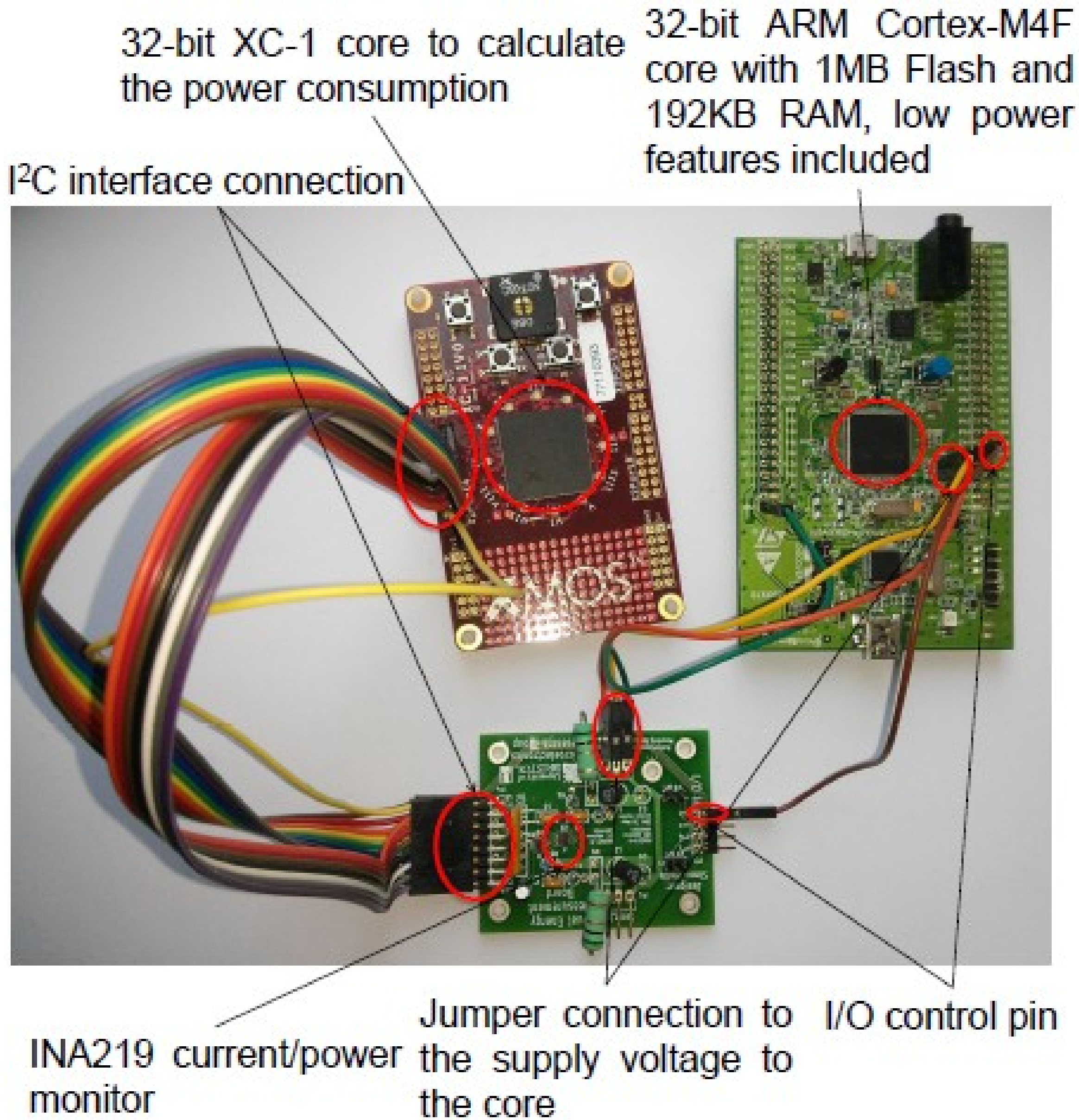
S. Kerrison and K. Eder, 2013. "Energy Modelling of Software for a Hardware Multi-threaded Embedded Microprocessor ", under review at ACM TECS.

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

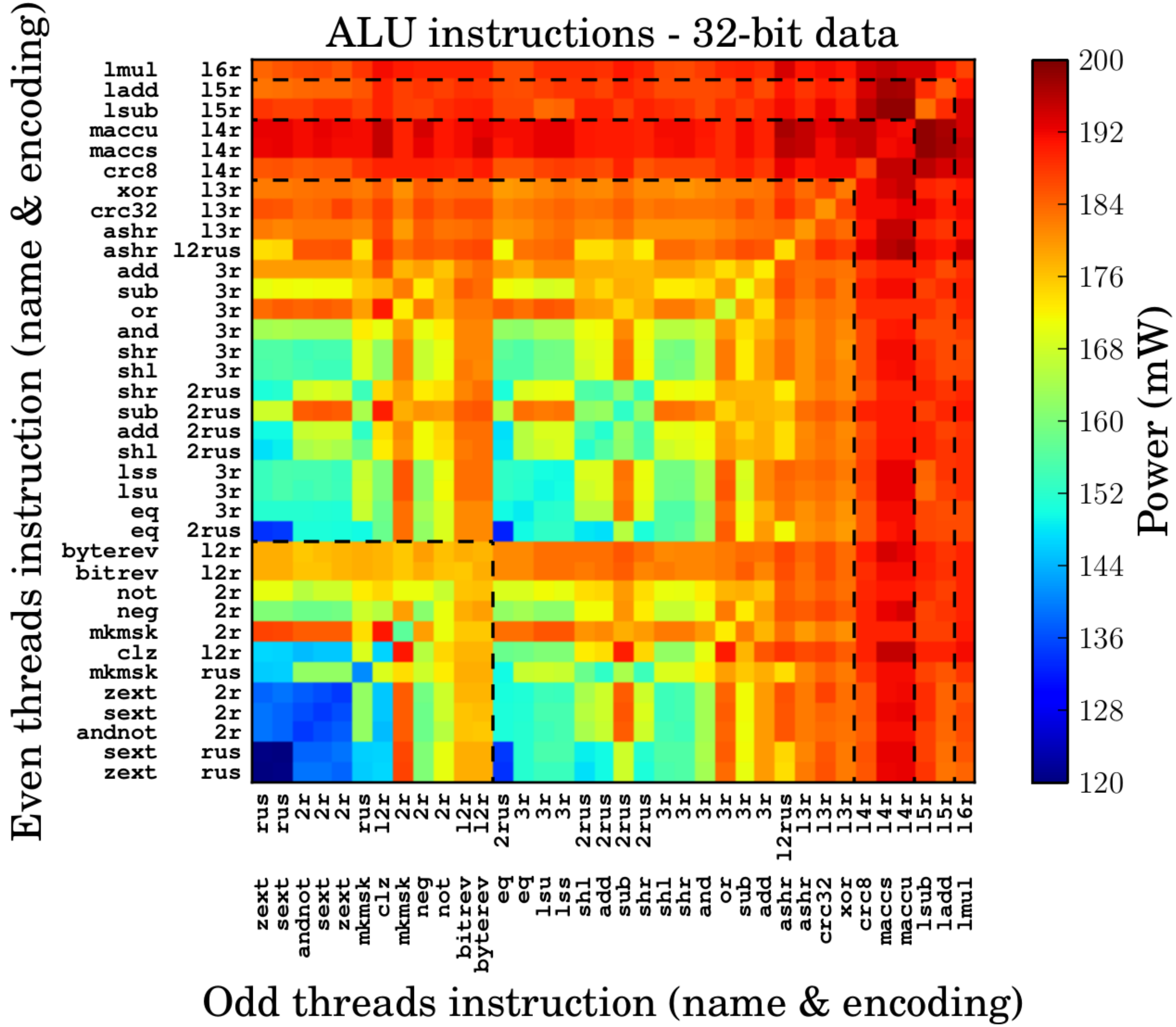
University of BRISTOL

The Setup...



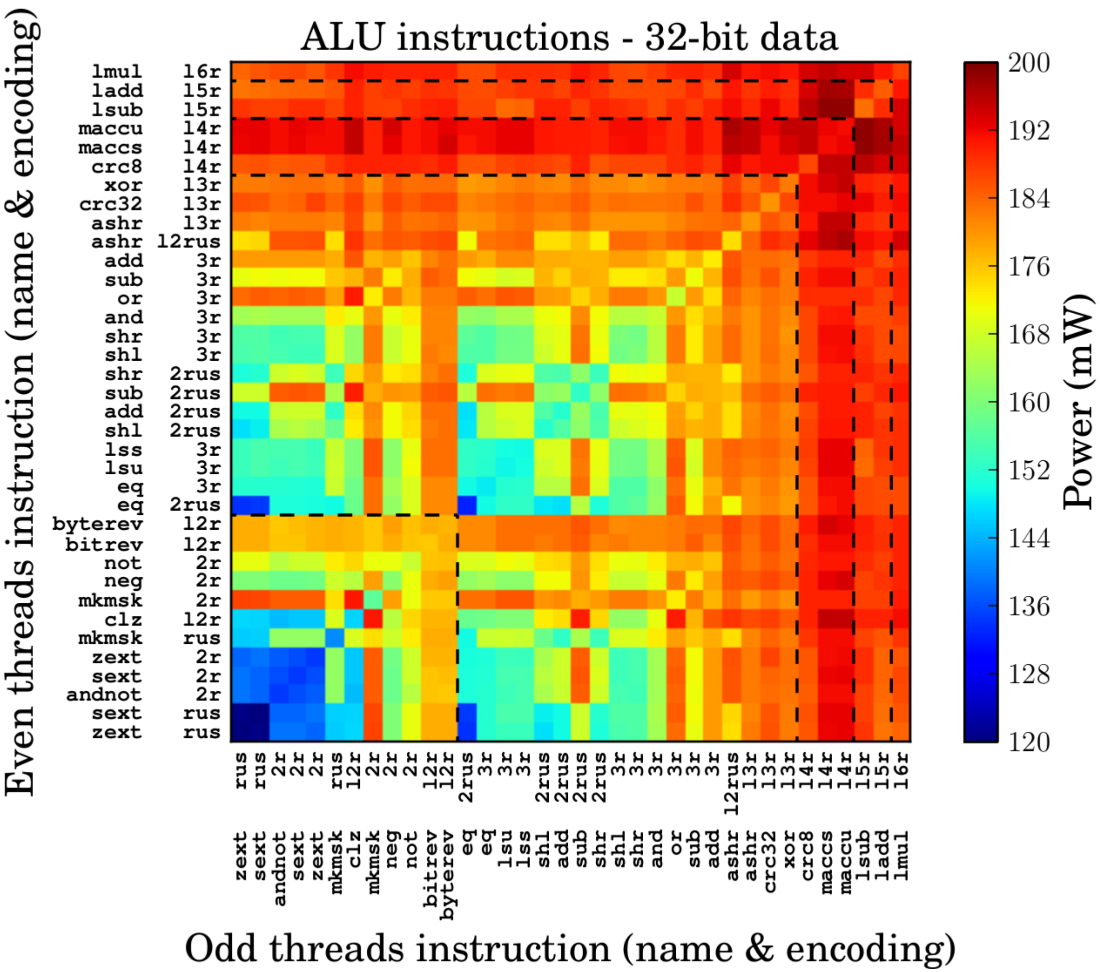
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

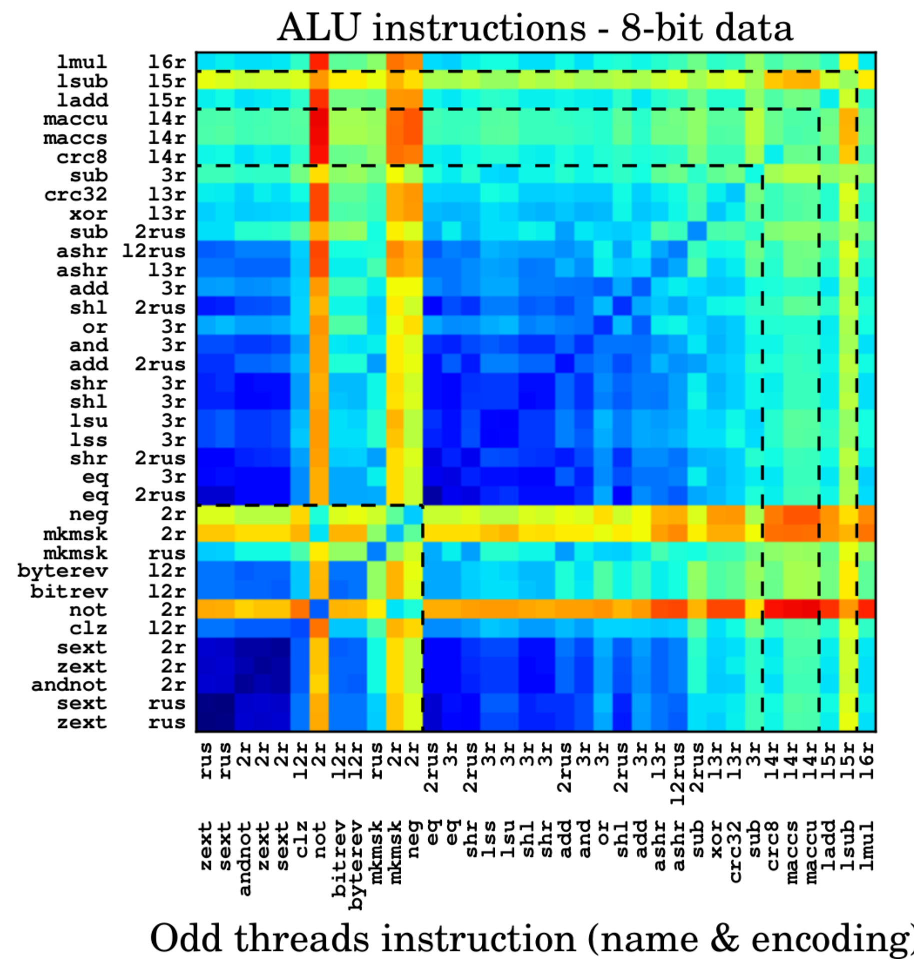
ISA Characterization



Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

ISA Characterization



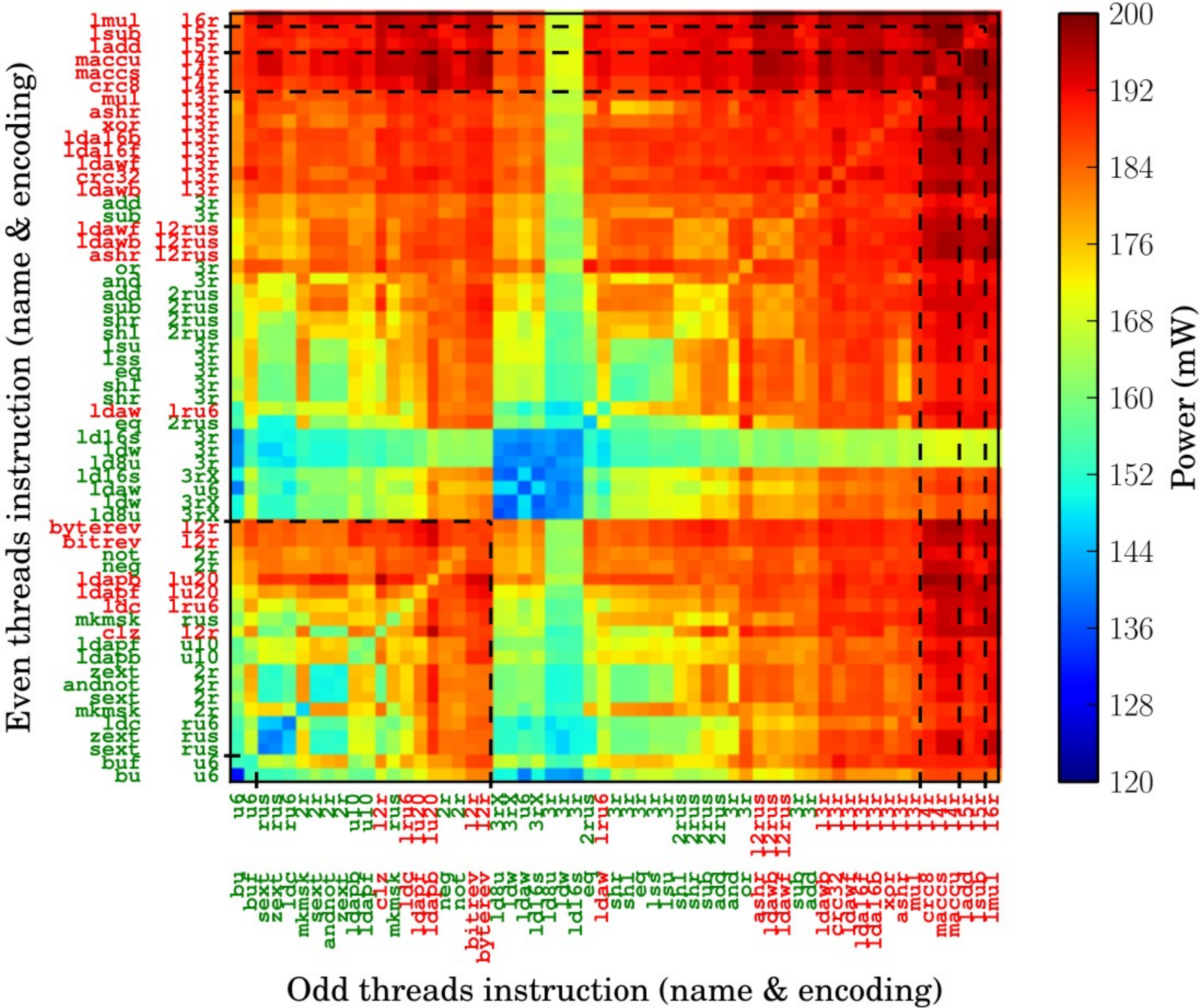


EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

ISA Characterization



Resource Usage Analysis

Static Analysis for Energy Transparency and Optimization

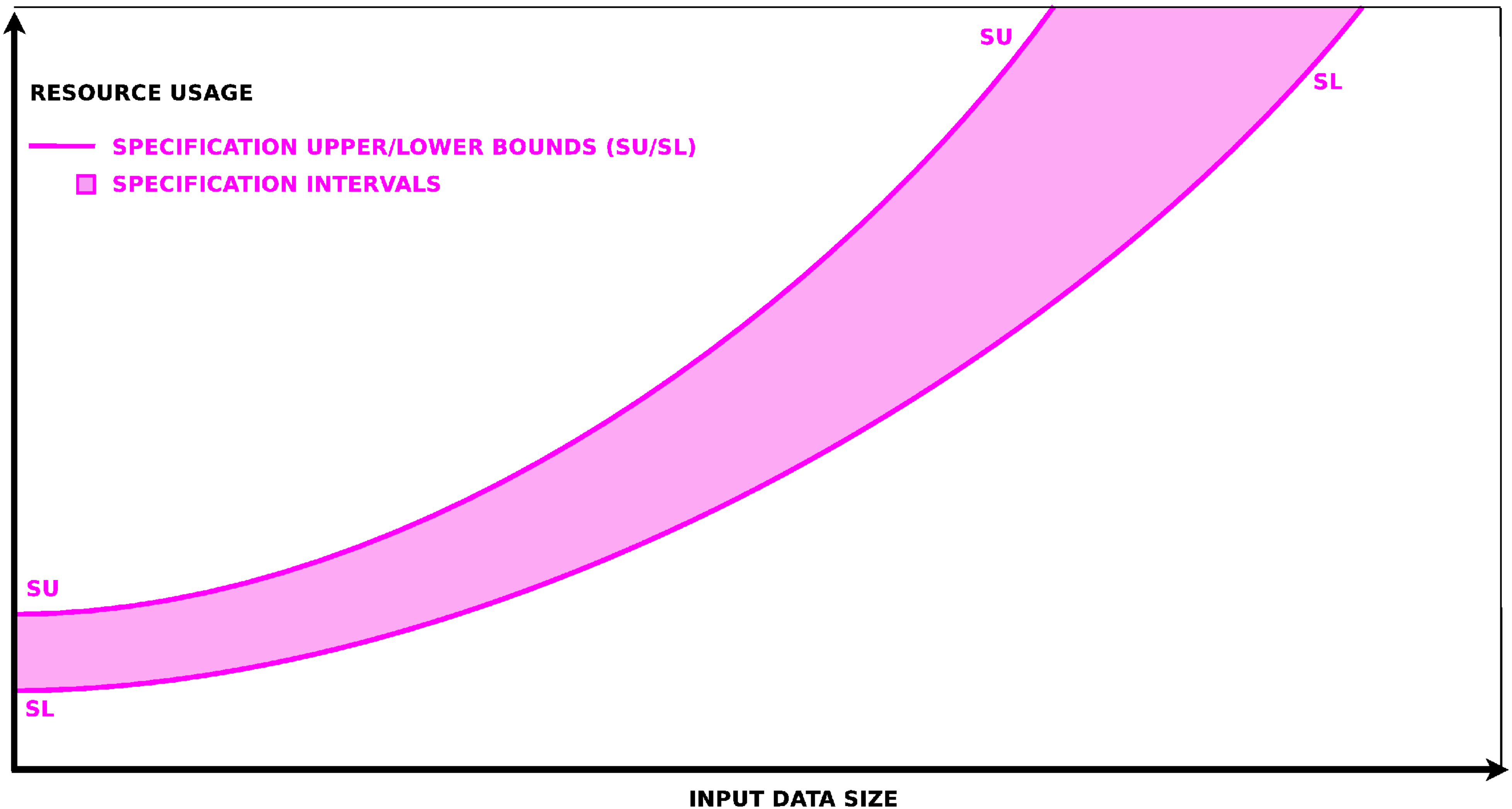
Resource Usage Analysis

- Adaptation of advanced cost and WCET analysis techniques to energy consumption
- Techniques for automatically inferring both upper and lower bounds on energy usage of a procedure
- Bounds expressed using monotonic arithmetic functions per procedure depending on input data sizes or any other properties (e.g. location)
  - Bounds are safe and also as accurate as possible
- Verification can be done statically by checking if the upper and lower bounds on energy usage and any other resource defined in the specifications hold

•

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

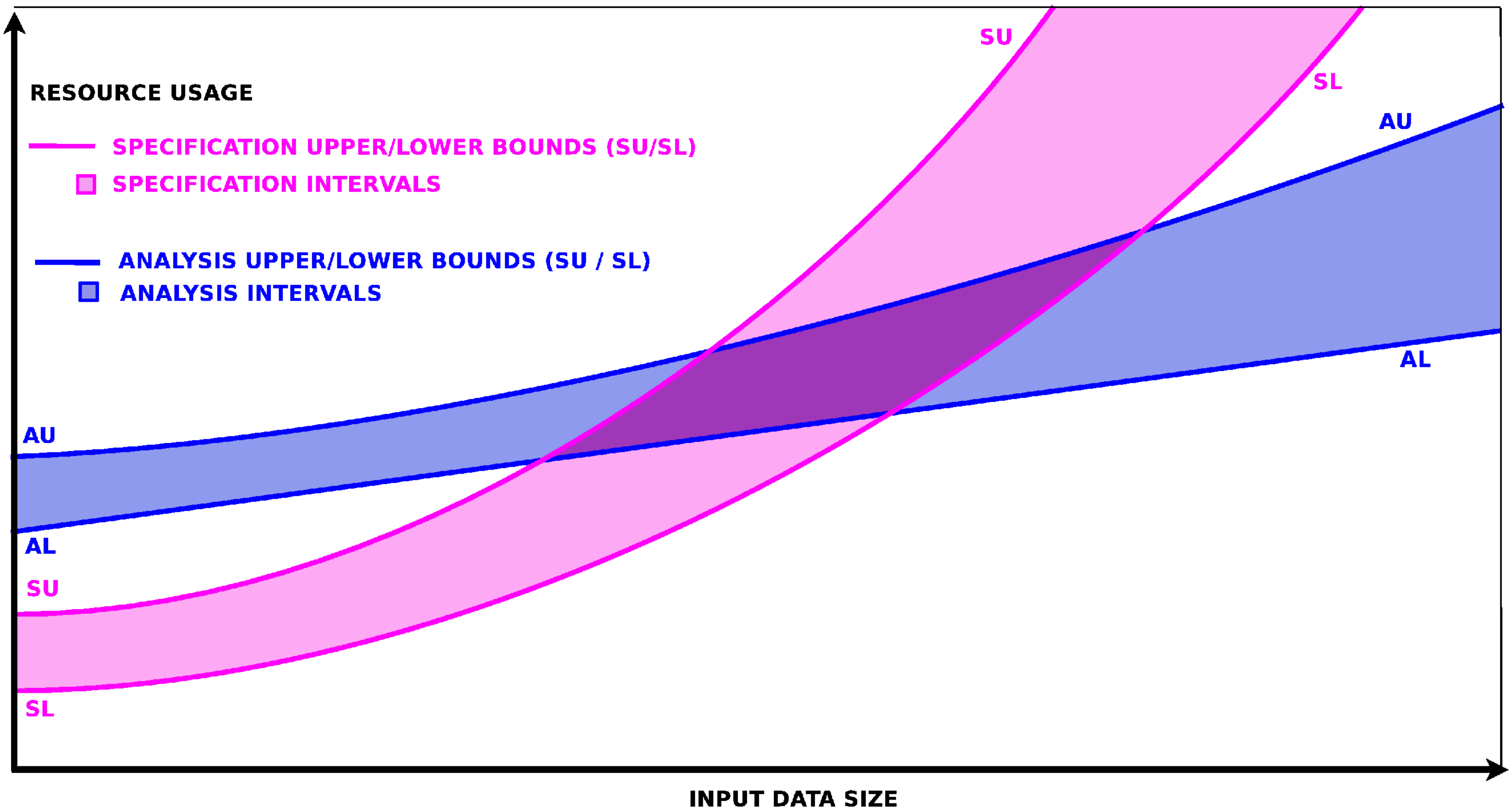
Specified Resource Usage



Source: Pedro Lopez Garcia, IMDEA Software Research Institute

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Analysis Result

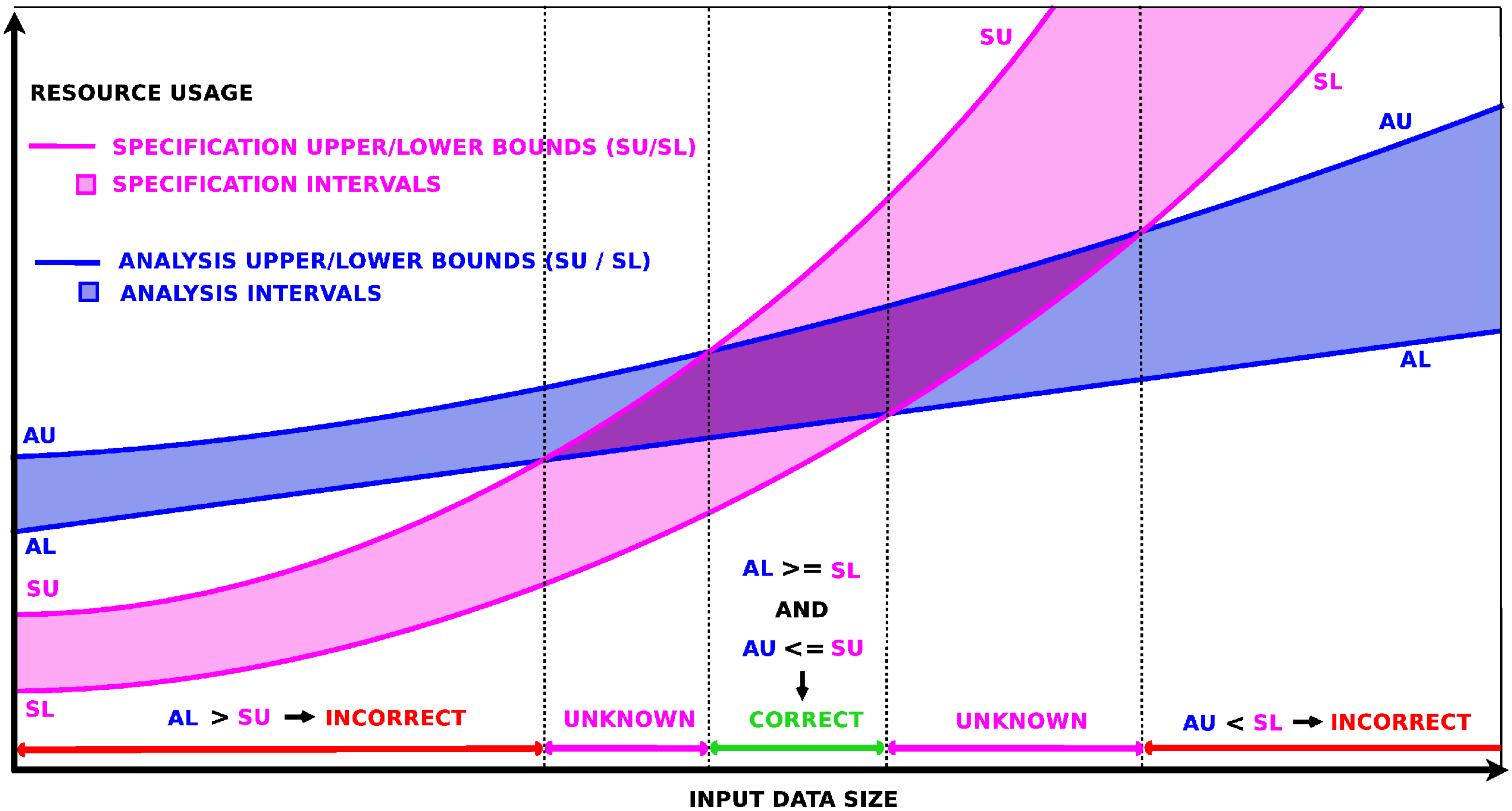


Source: Pedro Lopez Garcia, IMDEA Software Research Institute

INPUT DATA SIZE

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

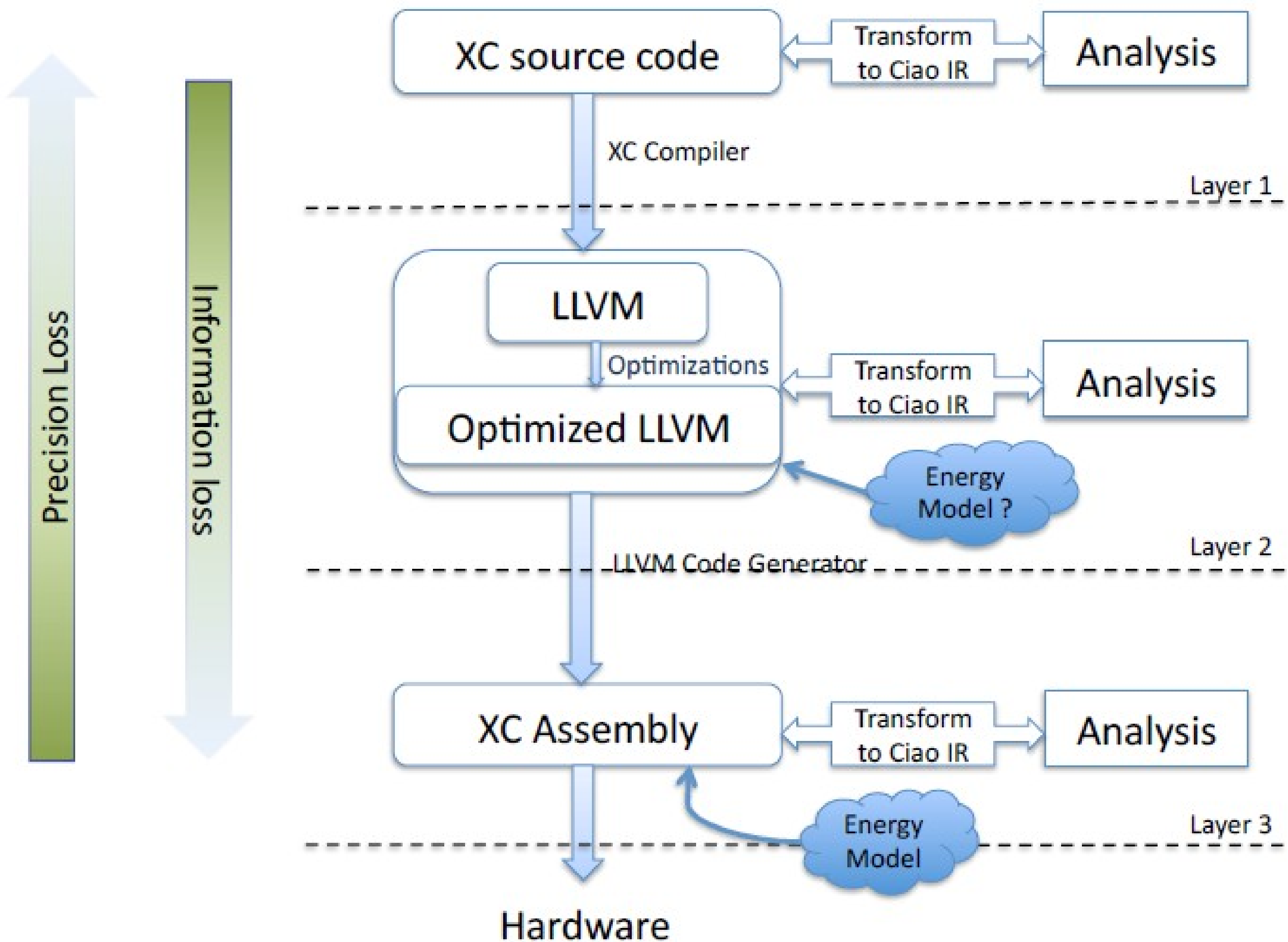
Verification



Source: Pedro Lopez Garcia, IMDEA Software Research Institute

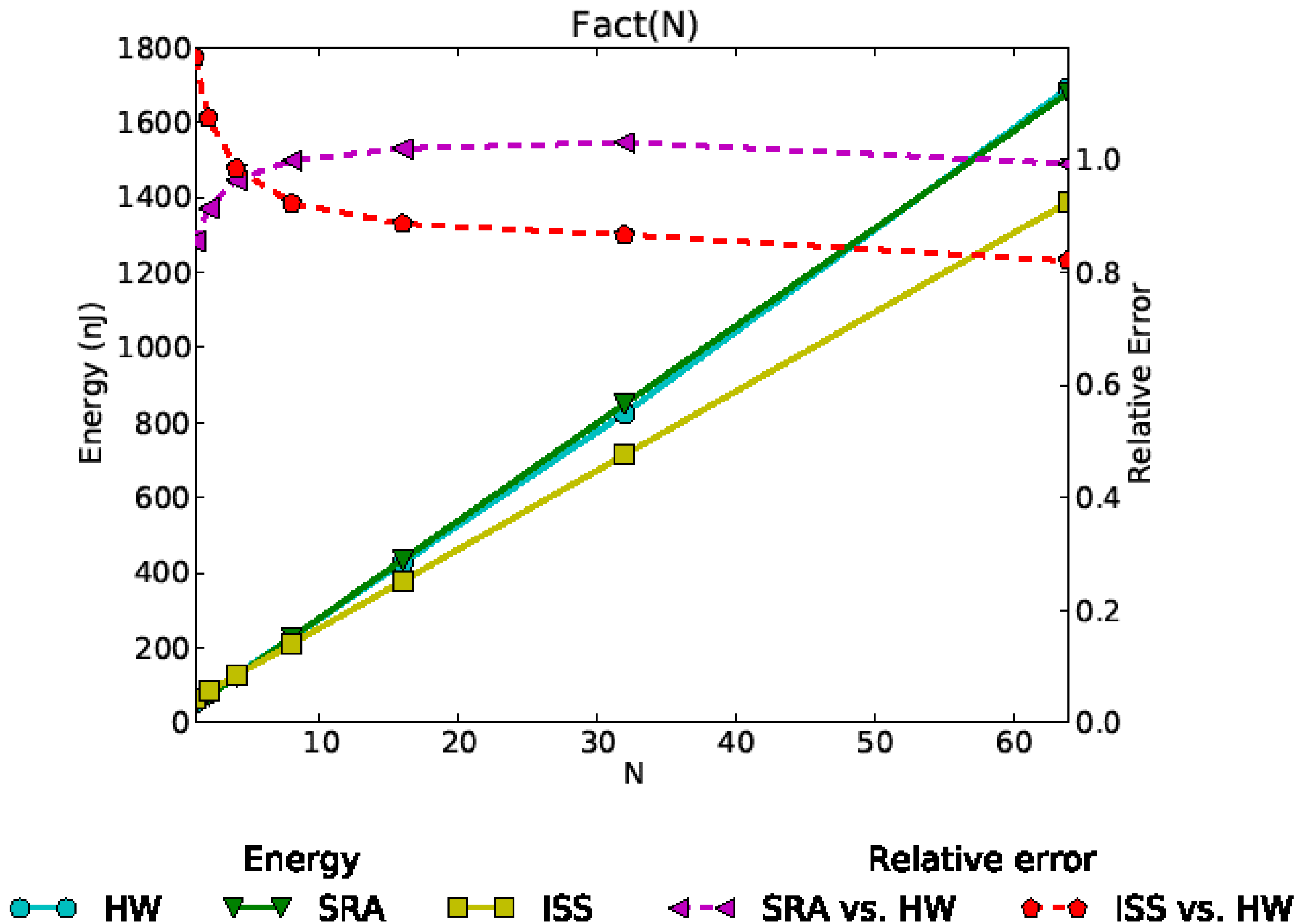
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Analysis Options



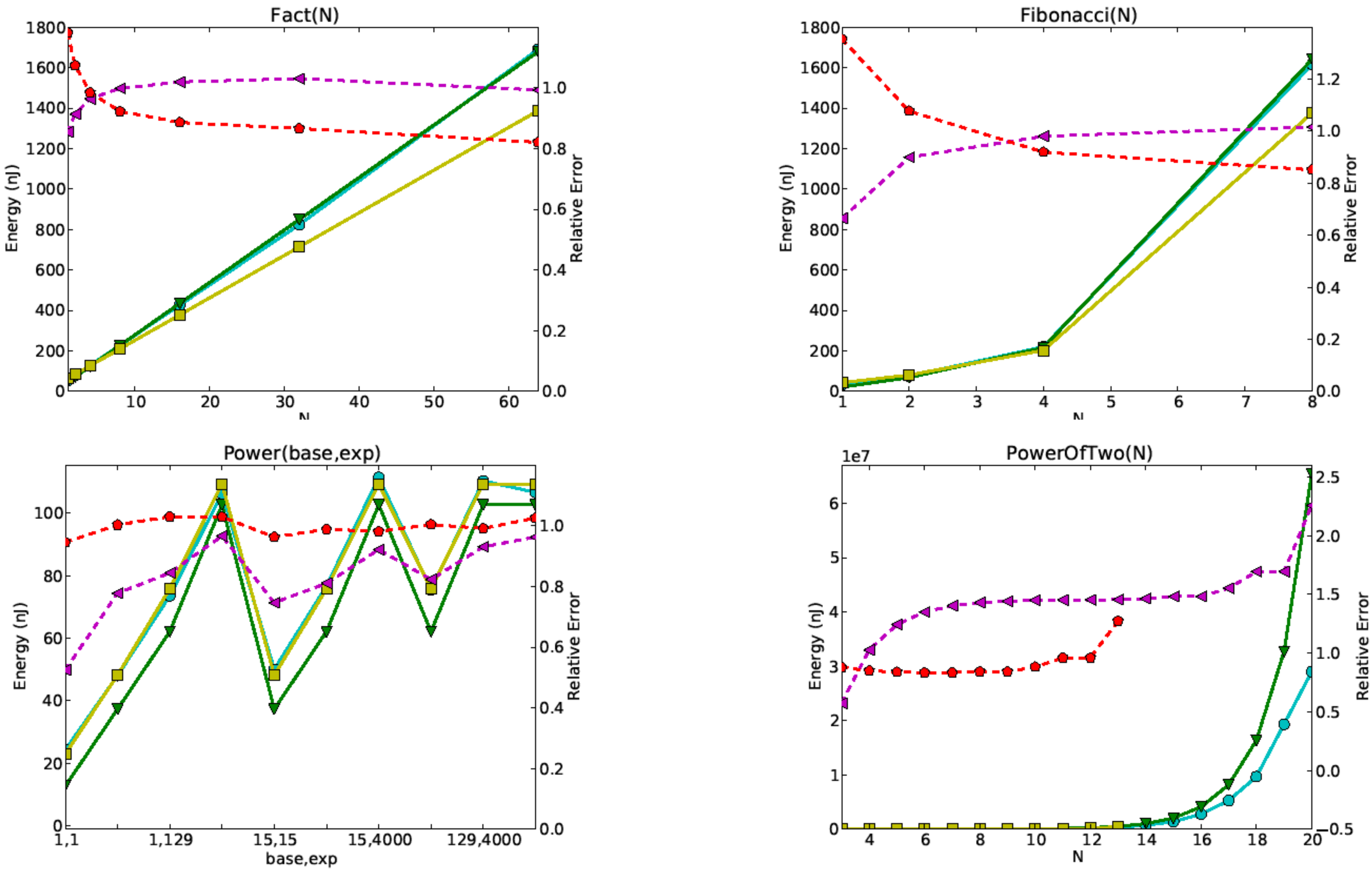
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

First Results



Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

First Results



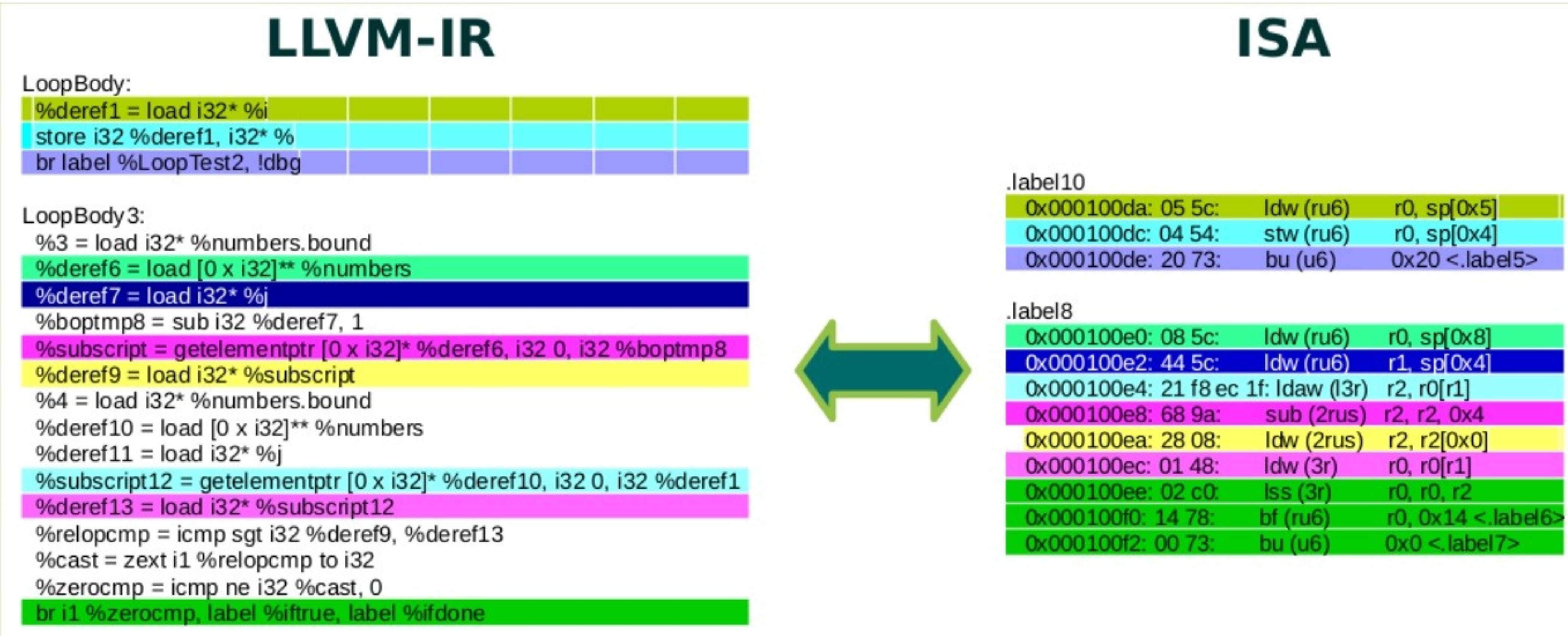
U. Liqat, S. Kerrison, A. Serrano, K. Georgiou, N. Grech, P. Lopez-Garcia, M.V. Hermenegildo and K. Eder. "Energy Consumption Analysis of Programs based on XMOS ISA-Level Models". LOPSTR 2013.

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

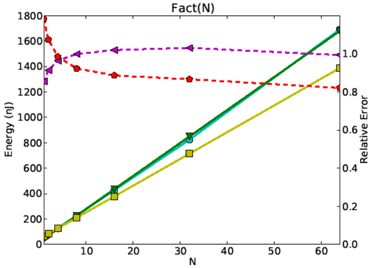
LLVM-IR to ISA Mapping



EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

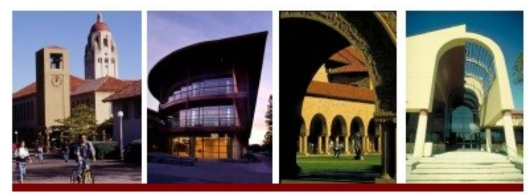
University of BRISTOL



Vision

- For HW designers:
  "Power is a 1st and last order design constraint."
  [Dan Hutcheson, VLSI Research, Inc., E³S Keynote 2011]

- "Every design is a point in a 2D plane."
  [Mark Horowitz, E³S 2009]



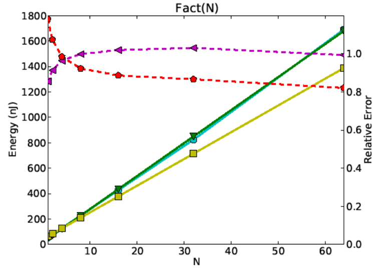
Scaling Power and the Future of CMOS

Mark Horowitz, EE/CS Stanford University

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

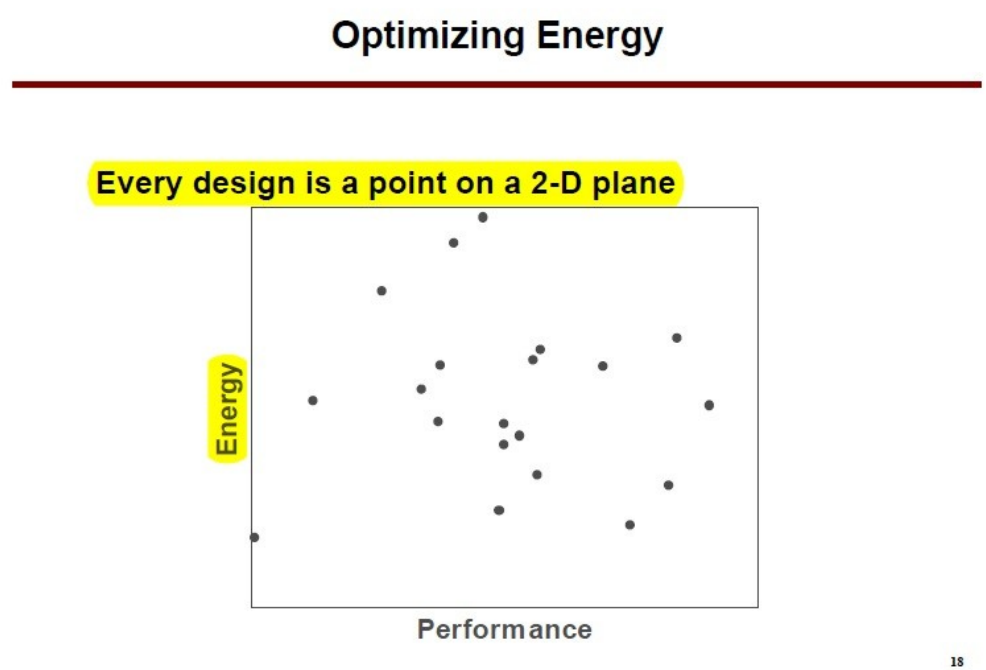
University of BRISTOL



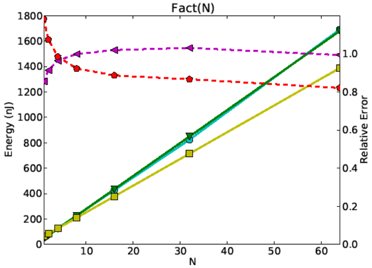
Vision

- For HW designers:
  "Power is a 1st and last order design constraint."
  [Dan Hutcheson, VLSI Research, Inc., E3S Keynote 2011]

- "Every design is a point in a 2D plane."
  [Mark Horowitz,E3S 2009]



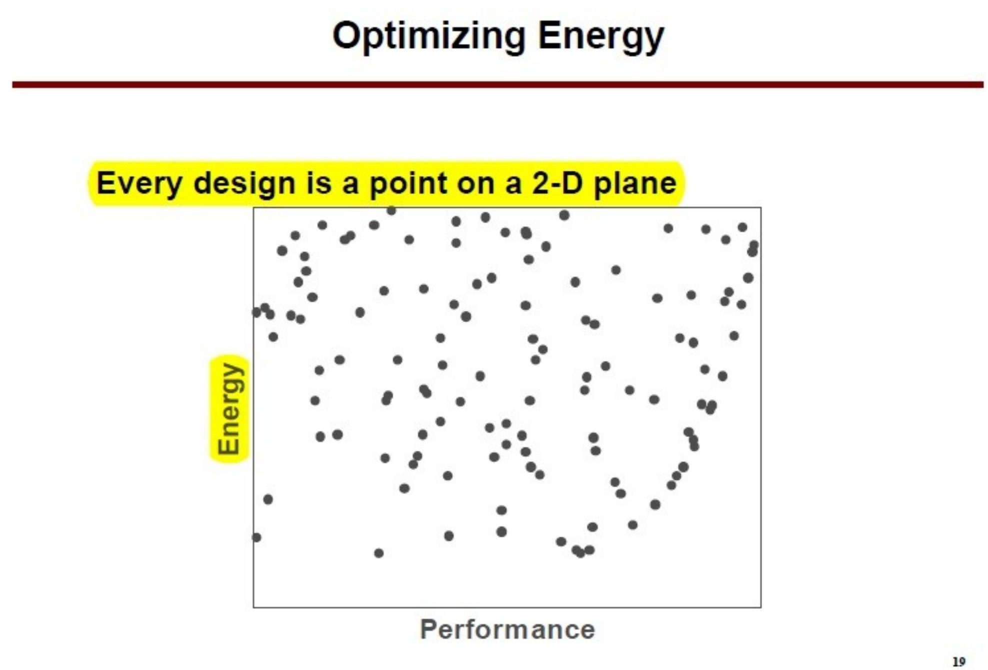
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license



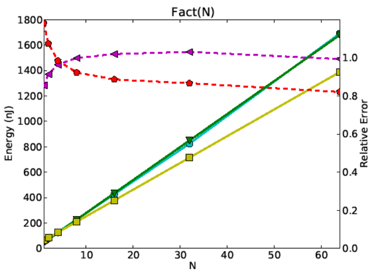
Vision

- For HW designers:
  "Power is a 1st and last order design constraint."
  [Dan Hutcheson, VLSI Research, Inc., E³S Keynote 2011]

- "Every design is a point in a 2D plane."
  [Mark Horowitz,E³S 2009]



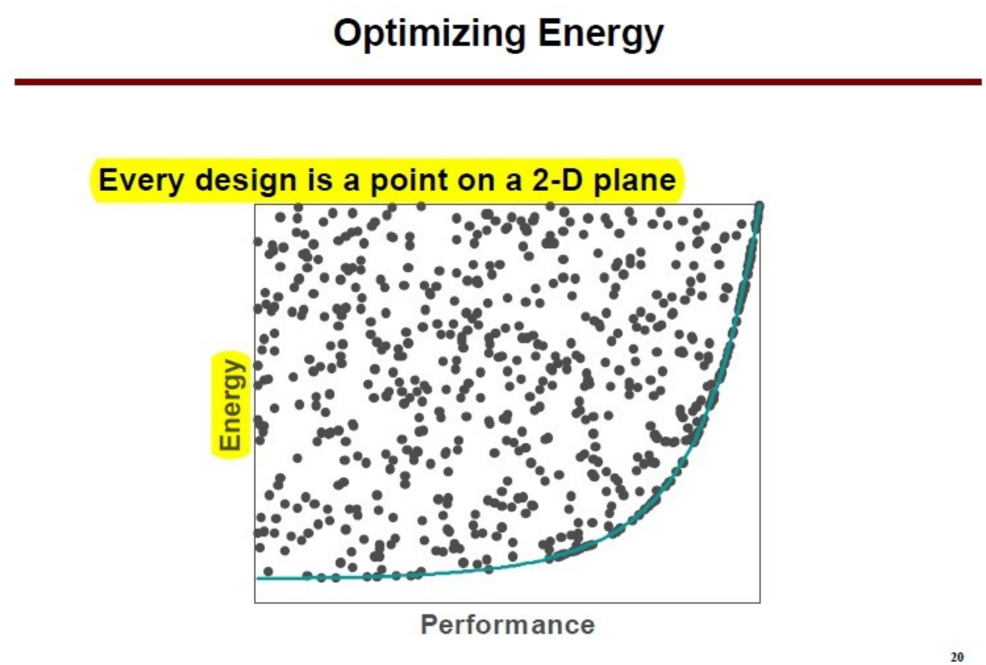
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license



Vision

- For HW designers:
  “Power is a 1st and last order design constraint.”
  [Dan Hutcheson, VLSI Research, Inc., E³S Keynote 2011]

- “Every design is a point in a 2D plane.”
  [Mark Horowitz, E³S 2009]



EMBECOSM®
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license
University of BRISTOL

More POWER to SW Developers

```
in 15ms do {...}
```

```
in 29000uJ do
{...}
```

- Energy Transparency from HW to SW
- Location-centric programming model

- **“Cool” code**

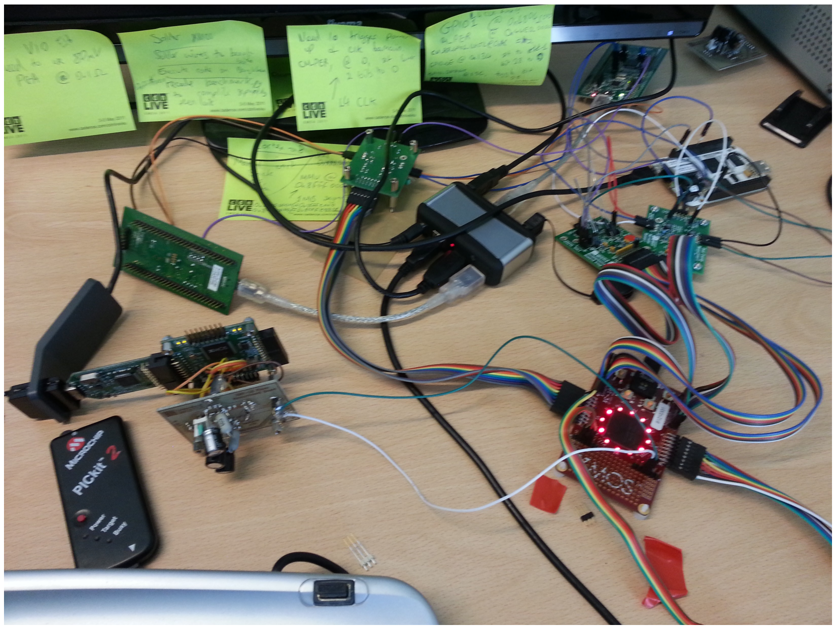
  A cool programming competition!

Promoting energy efficiency to a 1st class SW design goal is an urgent research challenge.

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

The Impact of Compilers on Energy Usage

Do Compilers Affect Energy?



- Initial research in 2012 by Embecosm and Bristol University
- Now published *open access* in a peer-reviewed journal

Identifying Compiler Options to Minimize Energy Consumption for Embedded Platforms
James Pallister; Simon J. Hollis; Jeremy Bennett
The Computer Journal 2013; doi: 10.1093/comjnl/bxt129
http://comjnl.oxfordjournals.org/cgi/reprint/bxt129?ijkey=aA4RYlYQLNVgkE3

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

What is MAGEEC?

Today we optimize for speed or space

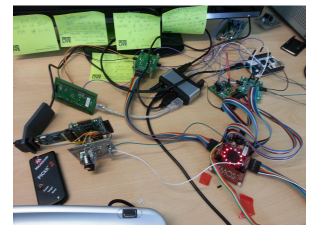
What if we could optimize for energy usage?

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

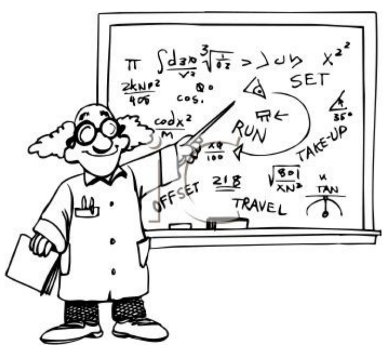
MAchine Guided Energy Efficient Compilation



Technology Strategy Board
Driving Innovation

Research into modeling energy usage

Energy measurement



MILEPOST

MAGEEC

Research into feedback directed optimization

EMBECOSM®

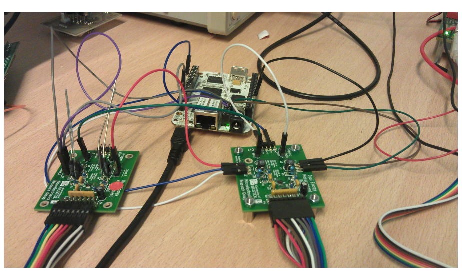
Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

What's New?

Objective is energy optimization

Generic framework: GCC *and* LLVM initially

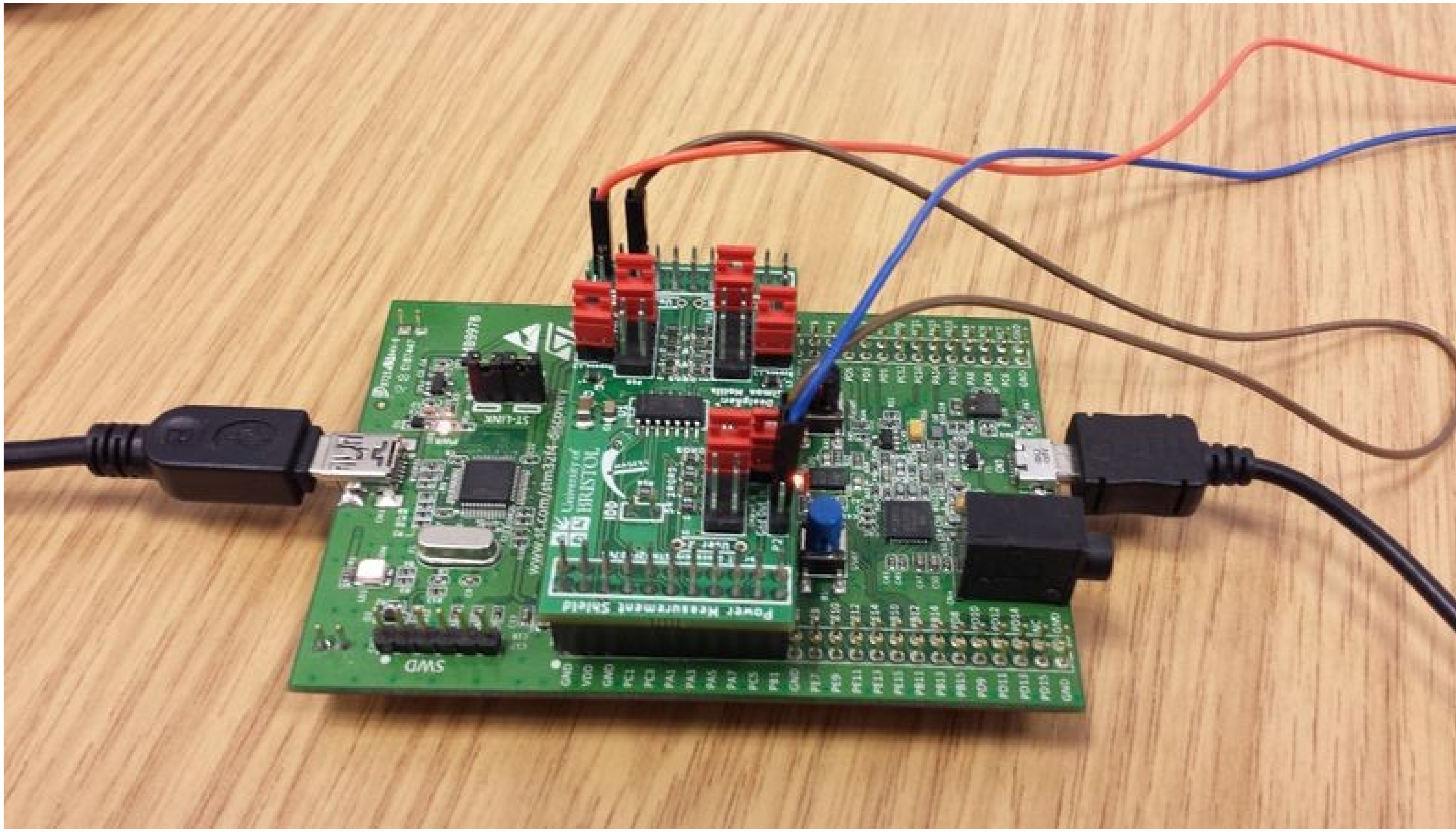


Energy measured *not* modeled

Working system, not research prototype

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

A Free and Open Source Energy Measurement System



mageec.org/wiki/Power_Sensing_Board

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

BEEBS
The Bristol/Embecosm Embedded Benchmark Suite

- A free and open source benchmark suite for embedded systems
  - expose different energy consumption characteristics
  - one benchmark can't trigger all optimisations
  - broad categories to be considered
  - integer, floating point, branch frequency, memory bandwidth

Name	Source	B	M	I	FP	T	License	Category
Blowfish	MiBench	L	M	H	L	Multi	GPL	security
CRC32	MiBench	M	L	H	L	Single	GPL	network, telecomm
Cubic root solver	MiBench	L	M	H	L	Single	GPL	automotive
Dijkstra	MiBench	M	L	H	L	Multi	GPL	network
FDCT	WCET	H	H	L	H	Single	None†	consumer
Float Matmult	WCET	M	H	M	M	Single	GPL	automotive, consumer
Integer Matmult	WCET	M	M	H	L	Single	None†	automotive
Rjindael	MiBench	H	L	M	L	Multi	GPL	security
SHA	MiBench	H	M	M	L	Multi	GPL	network, security
2D FIR	WCET	H	M	L	H	Single	None†	automotive, consumer

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Get Involved

Get Involved at FOSDEM

Developer room on Sunday

Energy Efficent Computing

Start 9:00am, Room AW1.26

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

Energy-efficient computing devroom

Room: AW1.126
Calendar: iCal, xCal

Event	Speakers	Start	End
Sunday			
Energy scavenging, battery life and should we build more power stations *Why energy-efficiency of hardware and software matters*	Jeremy Bennett	09:00	09:30
Measuring energy consumption in embedded systems	Simon Hollis	09:30	10:15
An approach for energy consumption analysis of programs using LLVM	Kerstin Eder, Kyriakos Georgiou, Neville Grech	10:15	10:45
spEEDO: Energy Efficiency through Debug suppOrt	David Greaves	10:45	11:45
Open Energy Measurement Hardware	James Pallister	11:45	12:15
Open Low Power Devices *meet the mbed open platform*	Emilio Monti	12:15	12:30
Measuring application energy consumption with instrumented hardware (workshop)	Andrew Back, Jeremy Bennett, Kerstin Eder, Simon Hollis, James Pallister, Simon Cook	12:30	15:30
MAGEEC *MAchine Guided Energy Efficient Compilation*	Simon Cook	15:30	16:15
EACOF: The Energy-Aware COmputing Framework	Hayden Field, Kerstin Eder, James Pedlingham	16:15	16:45

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Get Involved After FOSDEM

- MAGEEC
  - website: http://mageec.org/
  - wiki: http://mageec.org/wiki/MAGEEC
  - mailing list: http://mageec.org/cgi-bin/mailman/listinfo/mageec
- EACOF: https://github.com/eacof/eacof
- ENTRA: http://entraproject.eu/

- University of Bristol
  - PhD, summer projects, secondments, industrial collaborators.
  - EACO initiative: http://www.cs.bris.ac.uk/Research/Micro/eaco.jsp
- Embecosm: now hiring

EMBECOSM®

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license

University of BRISTOL

Thank You For Your Attention

Kerstin.Eder@bristol.ac.uk
Jeremy.Bennett@embecosm.com

Copyright © 2014 Embecosm and University of Bristol
Freely available under a Creative Commons license