CAPES/DAAD Cooperation on Reconfigurable Computing, invited talk, Sept 25, 2008, Universidade de Brasilia

Reiner Hartenstein

Our Computing Habits Unaffordable soon, and: a Climate Disaster

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The Solution: Reconfigurable Computing
mainly an education issue

The dominance of von-Neumann-centric computing is the root of massive energy [& cost] problems

(mono-rail education)

keep in mind

„You can always teach programming to a hardware guy ...

... but you can never teach hardware nor configware" to a programmer

keep in mind

The programmer population we need is not existing yet ...

...due to the yaw-dropping sclerosis of the joint IEEE-CS /ACM task force on Computing Curricula,

we need a dual-rail education

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outline

- **Introduction** ⇐
- Illustrating Reconfigurable Computing
- The von Neumann Syndrome
- The Impact of Reconfigurable Computing
- Dual-Rail Education
- Conclusions

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Greenland's Ice is Melting...
Our Computer Models Too Optimistic?

key issues

von Neumann / reconfigurable — keep in mind

climate change faster than predicted: by carbon emission, primarily from power plants ?

very high and growing computer energy cost - and growing number of power plants needed here

unaffordable soon?

the manycore programming crisis stalls progress (from growth industry to replacement industry ?)

the dominance of the von Neumann computer is the root of all these problems

keep in mind

CPU

FPGA

rDPA

software / configware

Reconfigurable Computing is the highly effective alternative

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Our Computing Ecosystem

Visible and hidden Computers everywhere:

In PCs, laptops, and in their peripherals in offices, homes and elsewhere

In entertainment equipment at home and elsewhere

In data centers, server farms and supercomputers

In base stations of wireless communication networks

In all kinds of machines in industry, homes and more

In all kinds of vehicles, airplanes, trains, ships and more

In all kinds of portable equipment and more

This list is far from being complete

Energy Cost of Computing

Immense energy consumption of the internet

Amsterdam's electricity consumption: 25% to server farms

Google's annual electricity bill: > 50,000,000 $ (in 2005*)

Google, Microsoft ...: huge datacenters at Columbia River and ORNL benefits from Tennessee Valley Authority.

Google: patent for a "water-based data center„ using the ocean to provide power and cooling.

*) when Brent oil price was around 40$

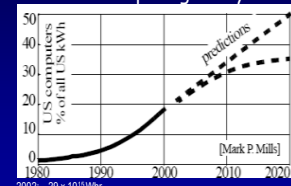
Pelamis Wave Energy Converter

Using the Ocean ?

Heating the Ocean to provide Cooling ?

computers' electricity bill

Electricity consumption by the US total computing ecosystem:

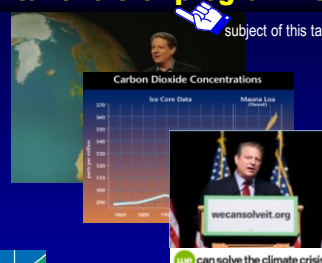


2002: 29 x 10^{15} Whr
29,000,000,000,000,000 Whr

'Engineers Will Solve This Problem' ... important role of programmers

Al Gore
Former next President of the United States
Author of "An Inconvenient Truth"

subject of this talk



Nobels Fredspris Konsert
November 10, 2007
with leading scientists, also from Universidade de Brasilia (UN ICPP)

we can solve the climate crisis.
A Generational Challenge to Repower America, July 17, 2008

Source: Mercury News, *Google, Intel Going Green, 2007
Source: wecansolveit.org 2008

'Engineers Will Solve This Problem' ... and programmers

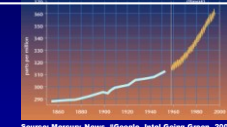
keep in mind

Software to Configware migration is the key

and

presenting a roadmap to solving this problem

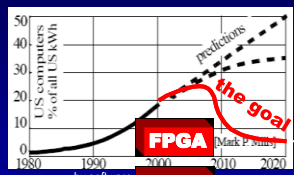
FPGA rDPA



Source: Mercury News, *Google, Intel Going Green, 2007
Source: wecansolveit.org 2008

Climate protection policy

Much more effect than any other climate protection effort ?



factor 10 ?
50% -> 5% ?
or even less ?

Side effect: saving the affordability of our computing infrastructure

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outline

Introduction
Illustrating Reconfigurable Computing
The von Neumann Syndrome
The Impact of Reconfigurable Computing
Dual-Rail Education
Conclusions

a mini tutorial

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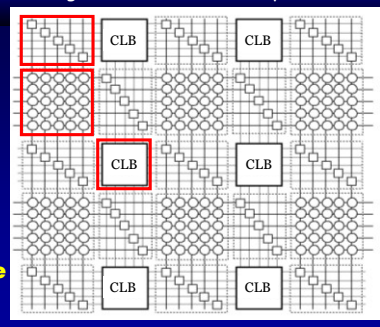
Field-Programmable Gate Array FPGA

FPGA

Xilinx (1984)

fine-grained reconfigurable



Xilinx old „island architecture"

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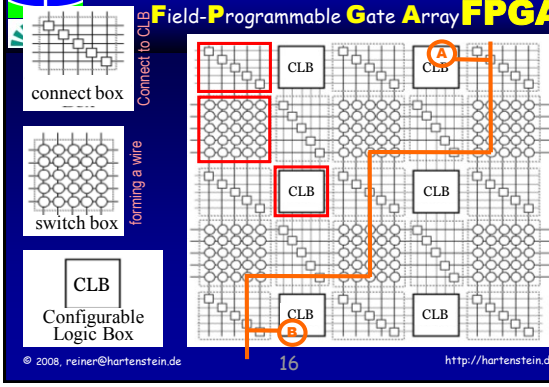
Field-Programmable Gate Array FPGA



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Field-Programmable Gate Array FPGA

Note:

this is Programming in Space .... FPGA

.... instead of Programming in time CPU

Remark:

Programming in high level language FPGA

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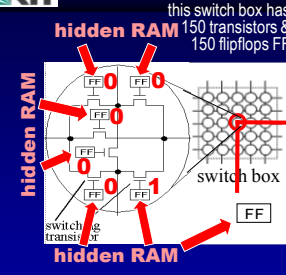
RAM-based interconnect



configware code loaded **before run time** into **"hidden RAM"**

Conclusions: why high speed-up?
only data streams at run time
no instruction fetch at run time

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Coarse-grained Reconfigurable

fine-grained: CLB Configurable **Logic** Box → CFB Configurable **Function** Box

datapath width:	1 bit	e. g. 16 bits, 32 bits, …
abstraction level:	logic gate level	functional level

rDPAs (reconfigurable DataPath Arrays) rDPA

rDPA: an array of **rDPUs** (reconfigurable DataPath Units)

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The silver bullet:
Reconfigurable Computing (RC)

RC beats the traditional computer: why?

instead of programming sequential execution:
it's programming the structure of the circuit …

… electrically – at the customer's site

Configware is used – not Software: FPGA

programming in space – not in time rDPA

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Massive Overhead Phenomena

overhead piling up to code sizes of **astronomic dimensions**

von Neumann CPU **single core** C++ compiler virtualization many other features

2006: C.V. "RAM" Ramamoorthy: **"von Neumann Syndrome"**

overhead (list not complete)	von Neumann machine
instruction fetch	instruction stream
state address computation	instruction stream
data address computation	instruction stream
data meet PU + other overh.	instruction stream
i / o to / from off-chip RAM	instruction stream

1986, E.I.S. Projekt: 94% for address computation
total speed-up: **x 15000**

PISA DRC accelerator [ICCAD 1984]

Early critics:
Dijkstra 1968: The Goto considered harmful
Koch et al. 1975: The universal Bus considered harmful
Backus, 1978: Can programming be liberated from the von Neumann style?
Arvind et al., **1983:** A critique of Multiprocessing the von Neumann Style

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manycore von Neumann: arrays of massive overhead phenomena

CPU many-core

overhead	von Neumann machine
instruction fetch	instruction stream
state address computation	instruction stream
data address computation	instruction stream
data meet PU + other overh.	instruction stream
i / o to / from off-chip RAM	instruction stream
Inter PU communication	instruction stream
message passing overhead	instruction stream
transactional memory overh.	instruction stream
multithreading overhead etc.	instruction stream

„a terrifying number of processes running in parallel, create sequential-processing bottlenecks **and losses in data locality**"
2008: David Callahan

proportionate to the number of processors

disproportionate to the number of processors

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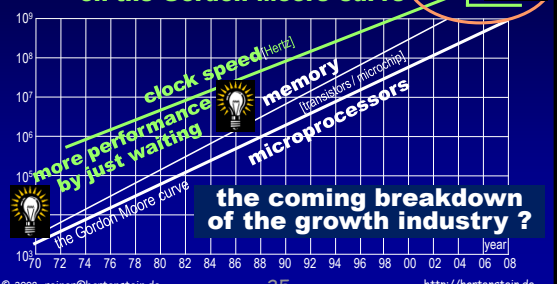
Why a growth industry ?

(microchips)

The end of this free ride on the Gordon Moore curve

stop in 2005

STOP



the coming breakdown of the growth industry ?

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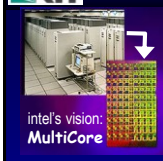
Break-through or Breakdown?



Industry is facing a disruptive turning point

The manycore programming crisis

forcing a historic transition to a parallel programming model yet to be invented [David Callahan]

It's an education, qualification, and a R&D problem

„I would be panicked if I were in industry"
[John Hennessy]

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Programmer population ...

...not existing for the transition from:

nor from:

von Neumann
CPU single core

to:

Reconfigurable Computing

saving energy

nor:

von Neumann
CPU single core

to:

many-core

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outline

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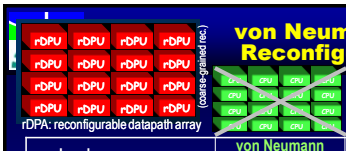
von Neumann overhead vs. Reconfigurable Computing



overhead	von Neumann machine	anti machine
instruction fetch	instruction stream	none*
state address computation	instruction stream	none*
data address computation	instruction stream	none*
data meet PU + other overh.	instruction stream	none*
i / o to / from off-chip RAM	instruction stream	none*
Inter PU communication	instruction stream	none*
message passing overhead	instruction stream	none*
transactional memory overh.	instruction stream	none*
multithreading overhead etc.	instruction stream	none*

*) configured before run time

no instruction fetch at run time

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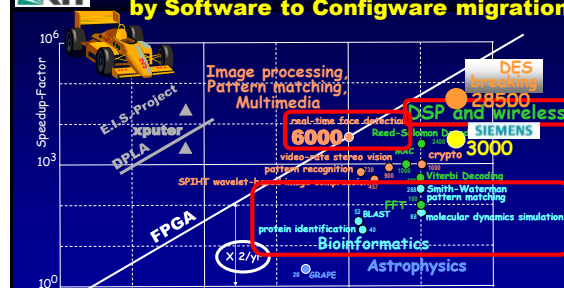
Speed-up factors obtained

by Software to Configware migration



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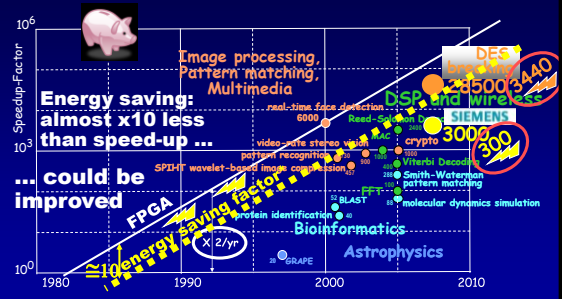
Energy saving factors obtained by software to configware migration



Demonstrating the intensive Impact

Platform (compared to Beowulf cluster)	Speed-up factor	Power saving factor
SGI Altix 4700 with RC 100 RASC	28514	3439

DES breaking [T. Elghazawi et al.: IEEE COMPUTER, Febr. 2008]

- when Hackers use FPGAs ...
- encryption on von Neumann unaffordable?

Reconfigurable Supercomputing

sgi - Silicon graphics - Reconfigurable Application-Specific Computing (RASC™)

Supercomputers with built-in FPGAs FPGA

for large scale software to configware migration

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Teaching properly

David Parnas (POIIP)

hardware: von Neumann / reconfigurable — keep in mind

The biggest payoff will come from putting old ideas into practice and teaching people how to apply them properly.

Dichotomy model for dual rail education to overcome the software/configware chasm & the software/hardware chasm

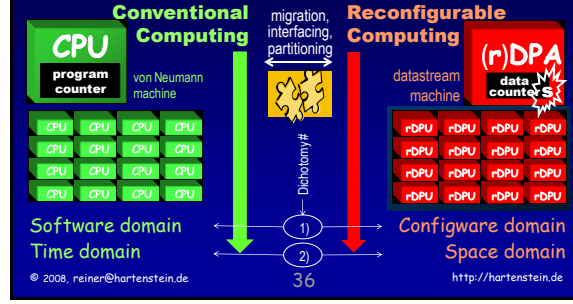
1) Machine **Paradigm Dichotomy** (von Neumann /Datastream machine): the **Twin Paradigm** model

2) **Relativity Dichotomy**: time domain / space domain – helps parallelization by time to space mapping

Dual-rail education

Yale Patt

The importance of not separating in your mind the notions of hardware and software



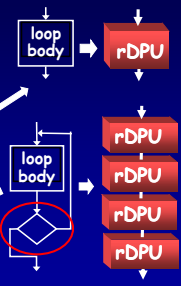
We need to POIIP for:

Software to Hardware Migration
and
Software to Configware Migration

2 simple key rules of thumb:

a) loop turns into pipeline [1979]

b) decision box turns into demultiplexer [1967]: PyOIIP



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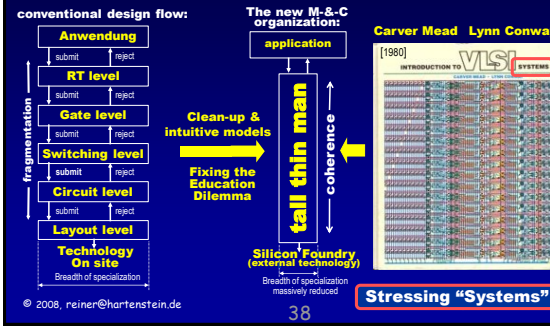
VLSI Education Revolution
avoiding specialization overload



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Following the exemplar: our ideal: The VLSI Revolution

comparable to our scenario

The brain child of:


Carver Mead


Lynn Conway

Solving the VLSI **design crisis:** missing designers, design tools (SW), HW for a design as a whole

Project has provided an educational framework to create a population of designers (and researchers) needed

incubator: EDA* industry, workstations…

The most influential research project in modern computer history.

text book [1980]
(Bestseller !)

*) Electronic Design Automation

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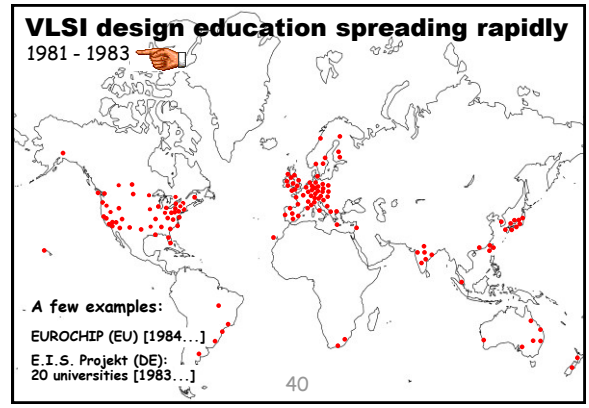
VLSI design education spreading rapidly
1981 - 1983



A few examples:

EUROCHIP (EU) [1984…]

E.I.S. Projekt (DE): 20 universities [1983…]

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Our Road Map

our dual-rail text book (in English):

preparing to call …

… for a mass movement …

… in dual rail CS education (& research)


our motivation

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Educating Professors

We are discussing to hold a summer school for Professors

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outline

- Introduction
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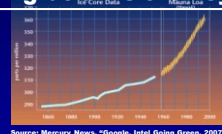
- **Conclusions**

We have presented a road map

and

FPGA rDPA

Software to Configware migration is the key



Source: Mercury News, "Google, Intel Going Green, 2007
Source: wecansolveit.org 2008

Conclusions

A von-Neumann-only strategy can never be the solution

We need a massive Software to Configware Migration

Established technologies are available and
we can still use standard software and their tools

Configware skills and basic hardware knowledge are essential qualifications for programmers.

We urgently need a fundamental CS Education and Research Revolution for dual-rail-thinking

We need „une' Levée en Masses“

- thank you for your patience

END

backup for discussion

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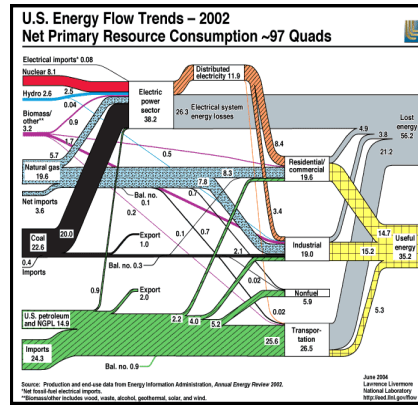
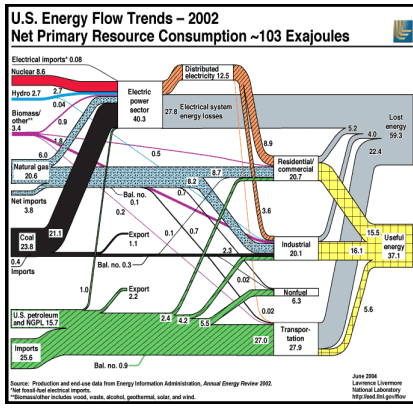
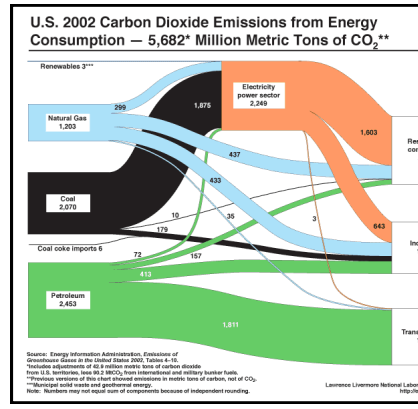
US Energy Flow 1



US Energy Flow 2



US CO_2 emission



quad: ~30,000 TWh

US energy in 2002:
total: 29000 TWh
electricity 8207 TWh
distributed 2323 TWh
wasted 6730 TWh
carbon dioxide emissions
total: 5,7 Gt
electricity: 2,5 Gt

tera = 10^{12}

2002: 29 x 10^{12} Wh

29,000,000,000,000 Wh 2002