GREENCOOL
A new Micro-scale Cooling Solution for Macro-scale Energy Efficiency

Arvind Sridhar, Mohamed M. Sabry, David Atienza
Embedded Systems Laboratory, EPFL

Liquid Cooling
... the next frontier in thermal packaging of electronics

Energy Efficiency in Data Centers
... an unexpected gift!

Power Usage Effectiveness
(ideally = 1)

PUE = \frac{Total\ Power\ Spent}{Power\ spent\ on\ the\ IT\ equipment}

Modern Air-Cooled Data Centers

Hot water-cooled Data Centers of the Future

Design determined by “worst case”
⇒ hottest spot governs cooling effort

Channel Modulation: a novel idea!

What if we “locally” customize the cooling effort for an IC?

Uniform Widths
⇒ Uniform cooling effectiveness
⇒ Large Thermal Gradients

Large widths
⇒ Less effective cooling
⇒ Lower pumping effort

Small widths
⇒ More effective cooling
⇒ Higher pumping effort

T, \ E = f (modulation_pattern)

Mathematical Model

Optimal Control

Search Iteration

Minimum reached?

Yes

End

Non uniform heating of complex microprocessors
⇒ Non uniform temperatures!

CHALLENGE #1

Water absorbs heat, inlet hotter than outlet
⇒ Temperature Gradients!

CHALLENGE #2

Modern Air-Cooled

Heated Surface

Hot water-cooled Data Centers

Heated Surface

Cost function

Constraints

Optimal Control

Search Iteration

Thermal-Aware Floorplanning

New Design

CHALLENGE #1

CHALLENGE #2

TWEAKING THE PHYSICS OF THE PROBLEM

2-die SUN Niagara multi-core processor

2-die 16-core Multiprocessor with DRAM

Full microarchitecture exploration

Full software benchmark exploration

total of 360 experiments

≤10°C
PUE=1.62
PUE=1.50
PUE=1.20

≤12°C
PUE=1.31
PUE=1.20
PUE=1.07

≤15°C
PUE=1.06
PUE=1.06
PUE=1.02

GREENCOOL 1.0* Minimizing Thermal Gradients

GREENCOOL 2.0 Maximizing Energy Efficiency

Up to 80% reduction in cooling energy

Theoretical Minimum Achieved

30% gradient reduction

≥30°C 37°C 37°C

≥ 47°C 47°C 55°C

≥ 20°C 50°C 100°C

Distance (mm)

Temperature Profile (°C)

Minimum Width

GREENCOOL

Maximum Width

Minimum Width

GREENCOOL

Maximum Width