3D Thermal-ADI
— A Linear-Time Chip Level Transient Thermal Simulator

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Characteristics of the 3D Thermal-ADI Simulator

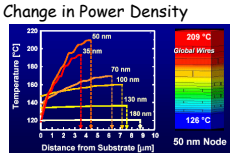
- A 3D Transient and Steady Thermal Simulator
- Linear Runtime and Memory requirement; Unconditionally Stable
- Steady State can be Reached in Ten Iterations
- Second Order Accuracy in Space and Time, i.e., the Truncation Error: $O[(\Delta x)^2,(\Delta y)^2,(\Delta z)^2,(\Delta t)^2]$
- Powered by Alternating Direction Implicit (ADI) Method for Fast Simulation
- Deal with Nonhomogeneous Cases and Boundary Conditions for VLSI Applications.

Motivation

- Scaling Trends Effects:
  - Chip Power and Area increases, but Negligible Change in Power Density
  - Current Density in Metal Lines Increases
  - Number of Metal Levels Increases

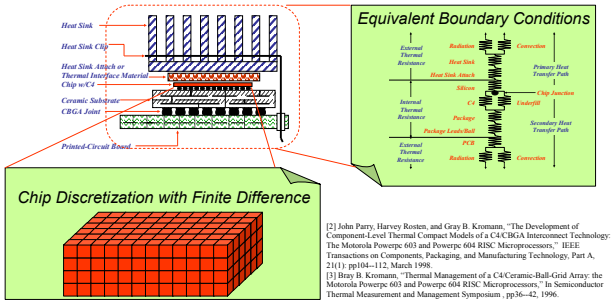
➔**What's Non-uniform Temperature Distribution?**

- Reliability Decreases as Temperature Increases:
  - Electromigration Time to Failure Decreases
  - Increased ρ (T) ➔ Wire Delay Increases



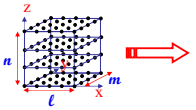
[1] Kaustav Banerjee, Massound Pedram, and Amir H. Ajami, " Analysis and Optimization of Thermal Issues in High-Performance VLSI," International Symposium on Physical Design (ISPD), pp230--237, April 2001.

Problem Formulation



[2] John Parry, Harvey Rosten, and Gray B. Kromann, "The Development of Component-Level Thermal Compact Models of a C4/CBGA Interconnect Technology: The Motorola Powerpc 603 and Powerpc 604 RISC Microprocessors," IEEE Transactions on Components, Packaging, and Manufacturing Technology, Part A, 21(1): pp104--112, March 1998.
[3] Bray B. Kromann, "Thermal Management of a C4/Ceramic-Ball-Grid Array: the Motorola Powerpc 603 and Powerpc 604 RISC Microprocessors," In Semiconductor Thermal Measurement and Management Symposium , pp36--42, 1996.

Key Idea: ADI Method



Total discretization points:

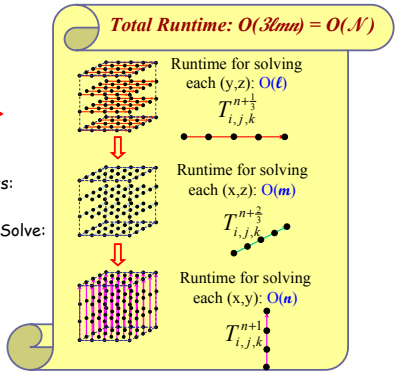
$N = \ell m n$

Finite Difference Problem to Solve:

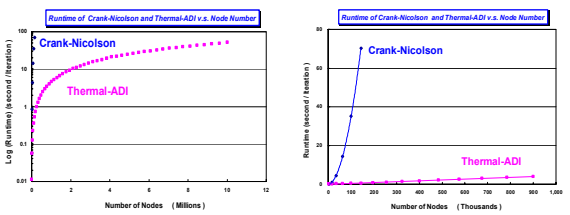
$A_{N\times N} x_{N\times 1} = b_{N\times 1}$

Fastest Runtime:

Superlinear

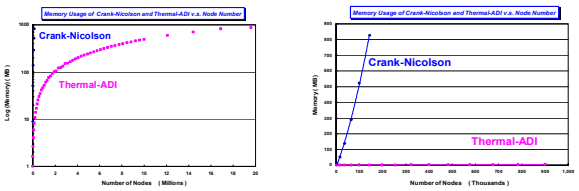


Linear Runtime



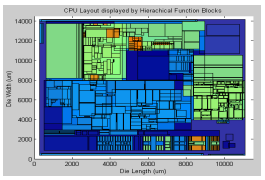
- Runtime Comparison of the Simulator based on the Crank-Nicolson Method and the 3D Thermal-ADI Approach.
- The runtime of the 3D Thermal-ADI Simulator is linearly proportional to the number of the discretization nodes.

Linear Memory Usage

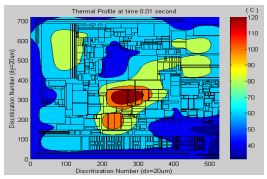


- Comparison of the Memory Usages of the Simulator based on Crank-Nicolson Method and the 3D Thermal-ADI approach.
- The memory usage of the 3D Thermal-ADI Simulator is linearly proportional to the number of the discretization nodes.

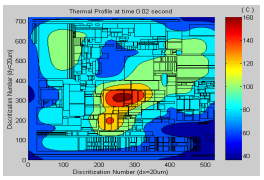
Transient Example



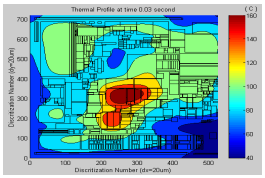
- Chip Size: 11.3mm × 14.4mm
- Total Power: 193.76 W
- Discretization Size:
  - $\Delta x = \Delta y = \Delta z = 20\ \mu m$
- Discretization Number: 565 × 720
- Time Increment: $\Delta t = 10^{-4}$ sec
- 1200 Iterations



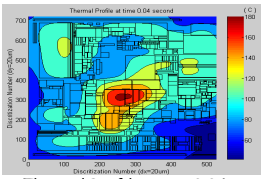
Thermal Profile at t = 0.01 sec



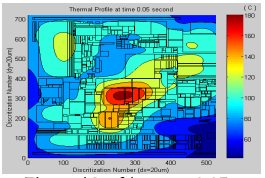
Thermal Profile at t = 0.02 sec



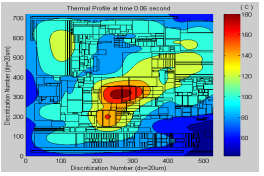
Thermal Profile at t = 0.03 sec



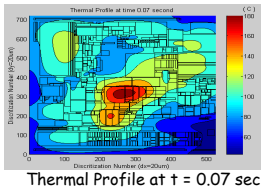
Thermal Profile at t = 0.04 sec



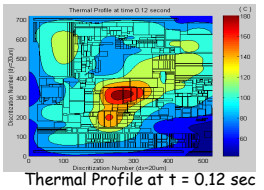
Thermal Profile at t = 0.05 sec



Thermal Profile at t = 0.06 sec

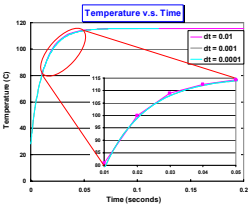


Thermal Profile at t = 0.07 sec



Thermal Profile at t = 0.12 sec

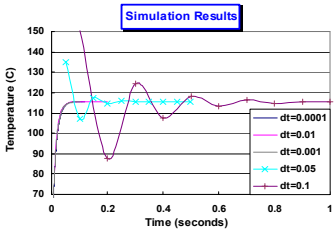
Transient Temperature Results vs. Time Increment



Δt= (sec)	0.0001	0.001	error	0.01	error
0.01	78.6482	78.6188	-0.037%	80.9795	2.96%
0.02	98.8244	98.8019	-0.023%	99.9774	1.17%
0.03	107.8540	107.8340	-0.019%	108.7870	0.87%
0.04	111.9820	111.9640	-0.016%	112.4710	0.44%
0.05	113.8860	113.8690	-0.015%	114.2370	0.31%
0.06	114.7660	114.7520	-0.012%	114.8870	0.11%
0.07	115.1740	115.1610	-0.011%	115.3100	0.12%
0.08	115.3630	115.3520	-0.010%	115.3630	0.00%
0.09	115.4500	115.4400	-0.009%	115.5210	0.06%
0.10	115.4900	115.4820	-0.007%	115.4570	-0.03%

- The transient results for a point at $T_{60,500,3}$ with Δt = 0.0001, 0.001, and 0.01.
- Less than 10 iterations are needed to reach steady state.

Number of Iterations to reach Steady State



- The steady state can be reached less than 10 iterations.
- If the time increment Δt is too big, the transient curve oscillates. However, the steady state can still be reached.

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