Statistical Power Profile Correlation for Realistic Thermal Estimation

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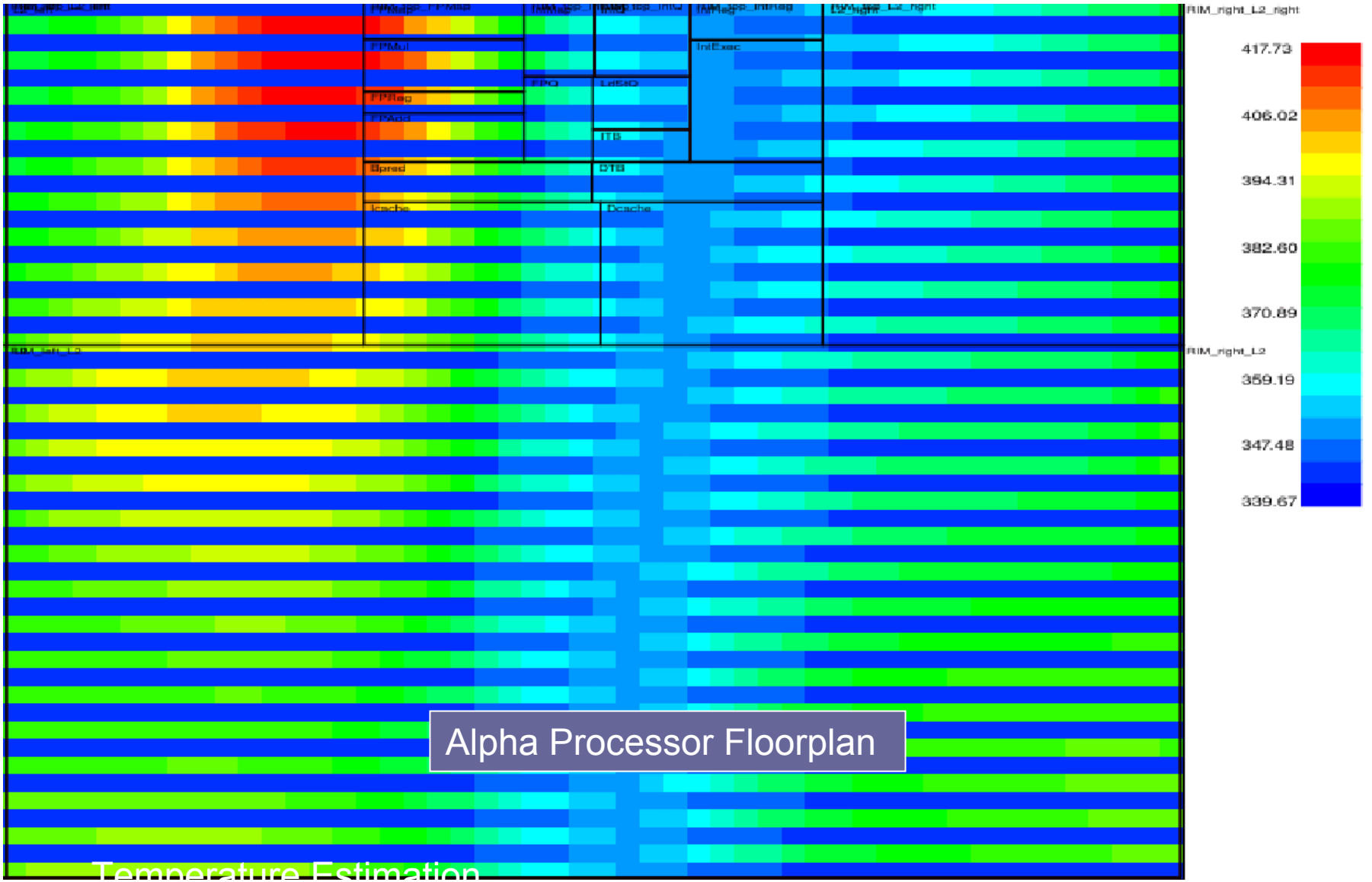
Thermal Estimation at Micro-architectural Level

- Avoids overheating of the chip
- Identification of temperature hotspots
- Design and placement of DTM techniques
- Thermal aware Floorplanning

Thermal Estimation



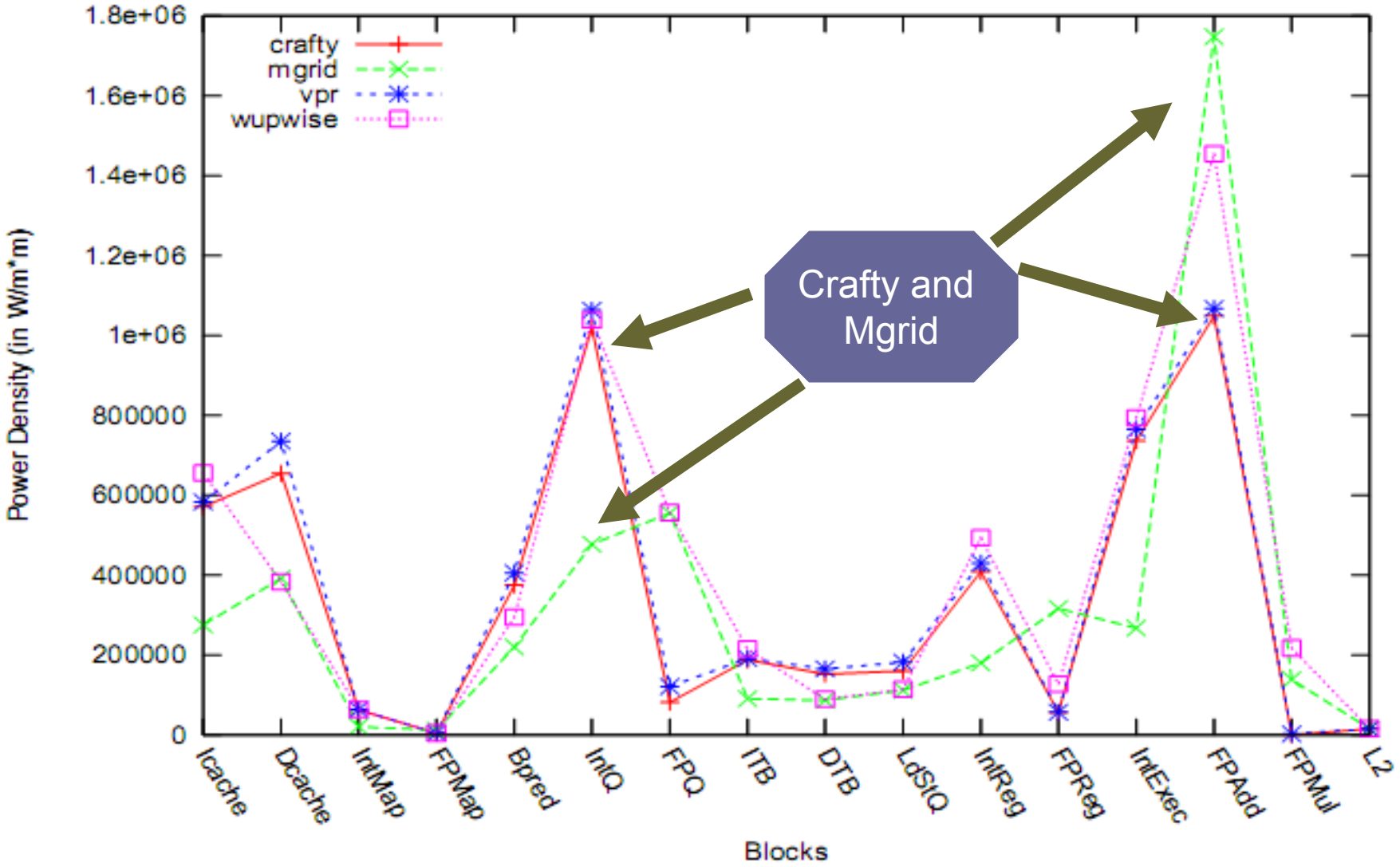
Alpha Processor Floorplan

Temperature Estimation

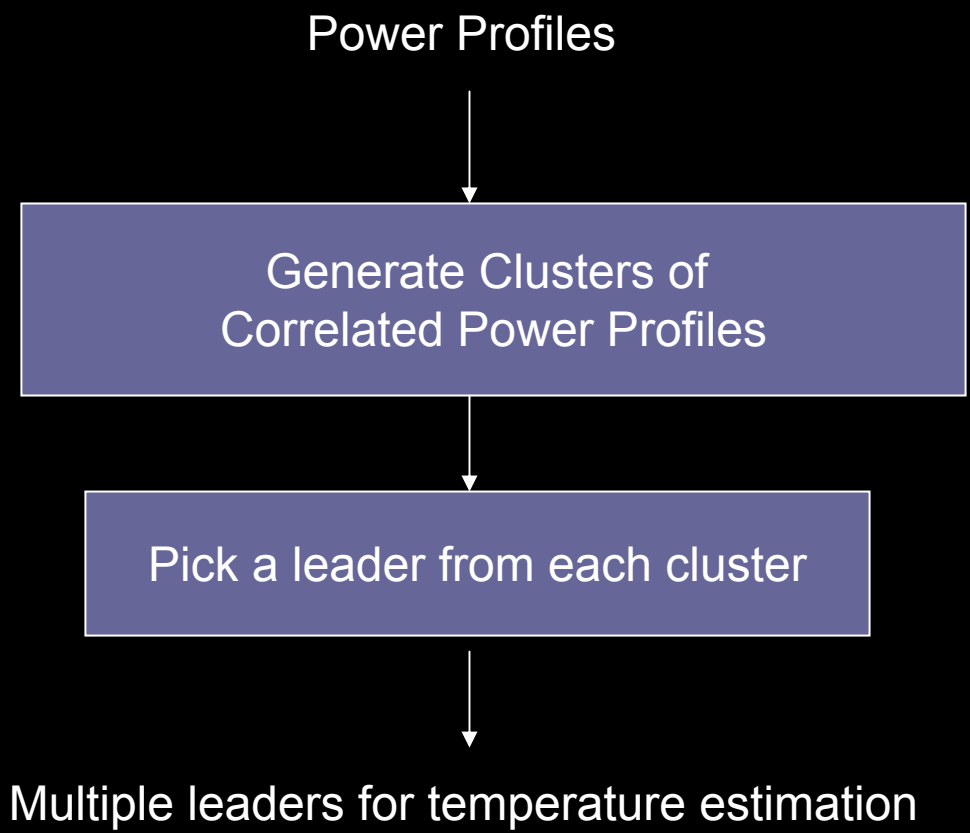
Average and Peak Power Profile

- Average Power Profile
  - Underestimates temperature
  - Misses hotspots
- Peak power Profile
  - Overestimates temperature
  - Detects false Hotspots
- Uncorrelated power profiles can add errors

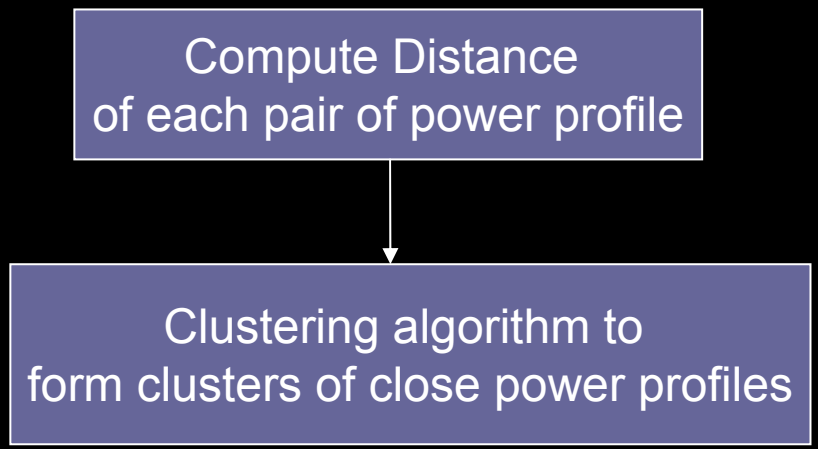
Effect of Correlation



Power Profile Pruning



Clustering Power Profiles

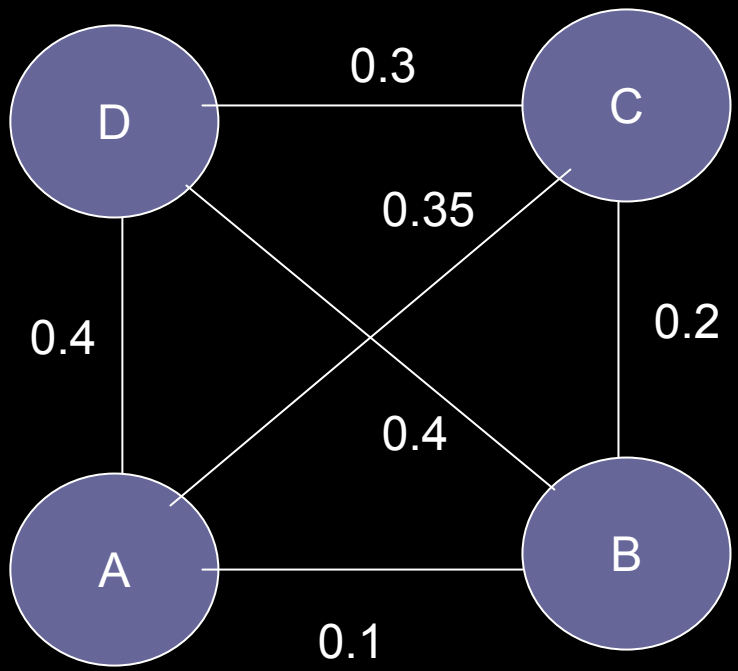


Clustering
of Power Profiles

- Statistical *Correlation* is used for computing closeness.
- $X = \{P_1, P_2, P_3, \ldots, P_m\}$
  where m is the number of blocks
- Correlation:
  $\rho_{XY} = E((X-\mu_X)(Y-\mu_Y)) / \sigma_X\sigma_Y$
- Distance:
  $d_{XY} = 1 - correlation\ \rho_{XY}$.

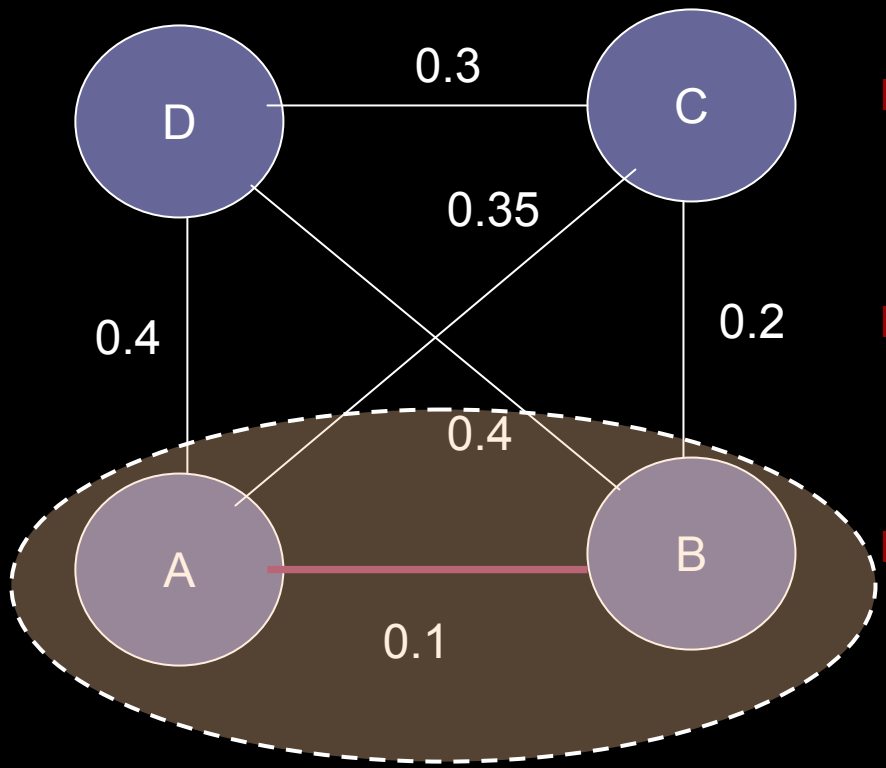
- Given number of clusters *K*, form clusters with minimum intra-cluster distance

K-Clustering Algorithm



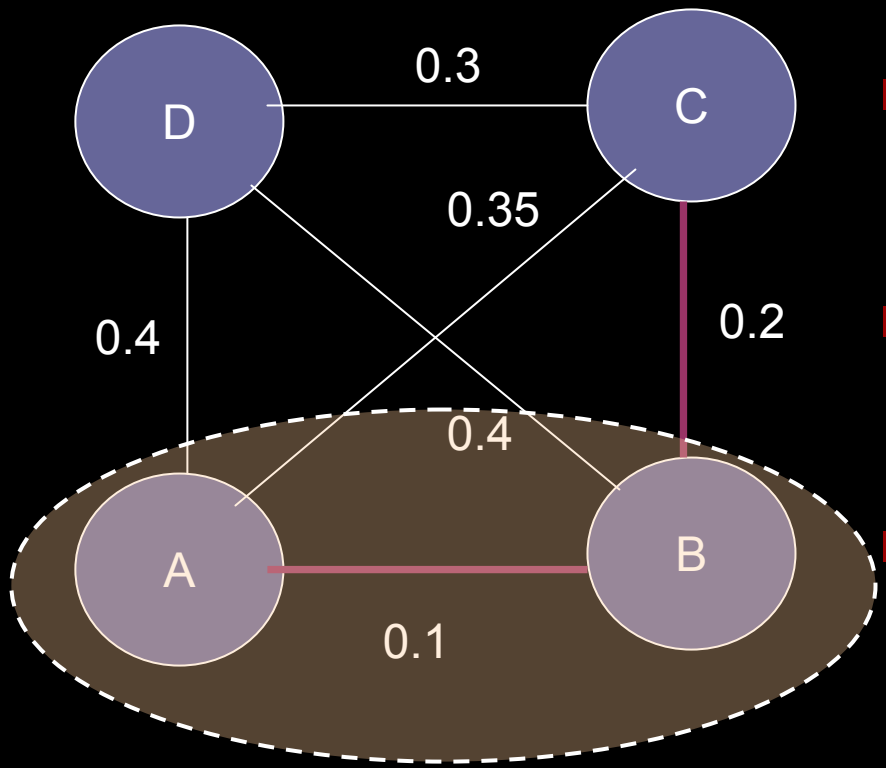
- Objectives:
  - Make K = 2 Clusters
  - Minimize δ
- Current Number of Clusters,
  - C = 4
- Current maximum intra-cluster Distance,
  - δ = 0

K-Clustering Algorithm



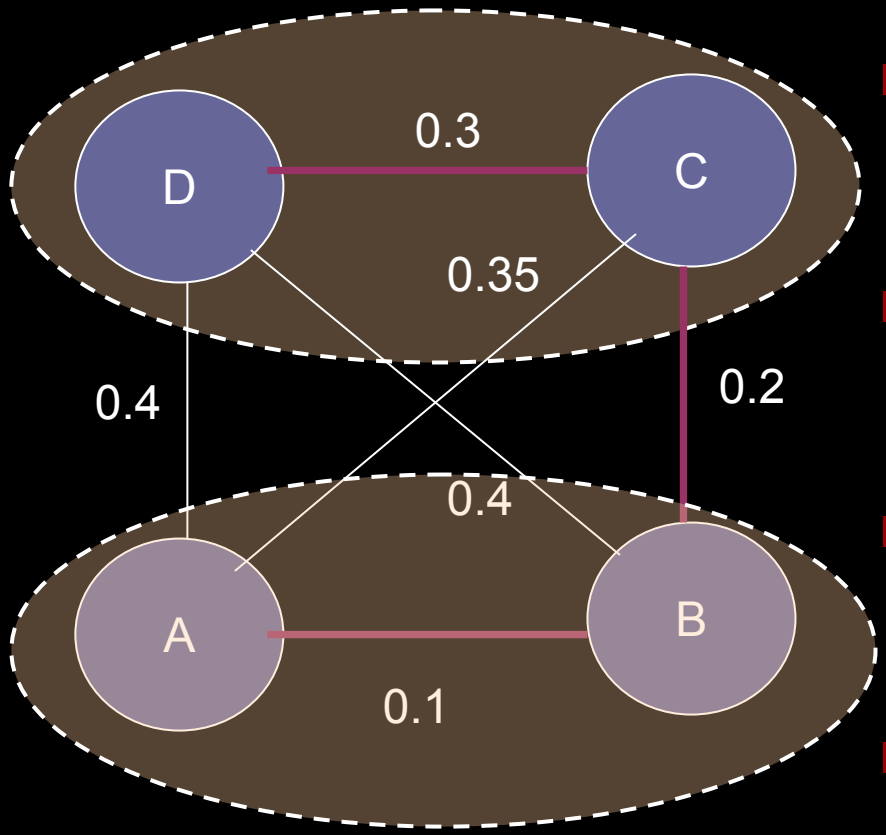
- Objectives:
  - Make K = 2 Clusters
  - Minimize δ
- Current Number of Clusters,
  - C = 3
- Current maximum intra-cluster Distance,
  - δ = 0.1

K-Clustering Algorithm



- Objectives:
  - Make K = 2 Clusters
  - Minimize δ
- Current Number of Clusters,
  - C = 3
- Current maximum intra-cluster Distance,
  - δ = 0.1

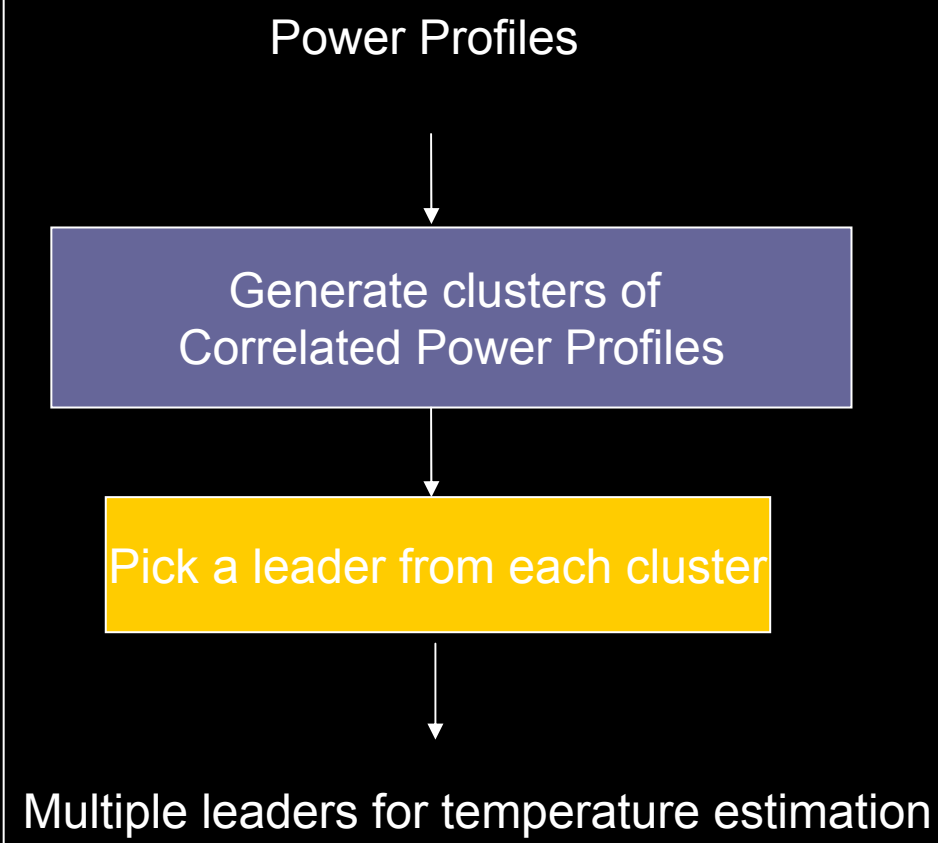
K-Clustering Algorithm



- Objectives:
  - Make K = 2 Clusters
  - Minimize δ
- Current Number of Clusters,
  - C = 2
- Current maximum intra-cluster Distance,
  - δ = 0.3
- Algorithm stops when

  C = K

Leader Power Profile



- Leader Selection:
  - Peak Power of all profiles in a cluster

Thermal Aware Floorplanner

- Simulated Annealing based Floorplanner
- Temperature in the cost function along with area, wire delay and wire length
- Modified version of *HotFloorplan*[1]
  - Temperature estimation using multiple leader power profiles
  - Leakage Power
    - Estimated using temperature feedback loop

[1] K. Sankarnarayanan et al. in Journal of ILP 2006

Experiments

- Alpha 21264 Microprocessor
- SimpleScalar and Wattch Power Simulator
- SPEC CPU 2000 Benchmarks
- HotLeakage for Leakage power

Results – Peak and Average

Floorplan Type	Maxim Wire Delay	ength	Peak Temperature
Multiple Power Profiles	**1.658**	**0.040**	363.5
Peak Power	2.276	0.048	3
Average Power	2.130	0.045	**366**

Improvement due to better estimation of temperature

Inaccurate estimation can lead to undetectable Hotspots

Results - Clustering

Number of Clusters	Maximum wire Delay		Peak Tempera-ure	Speed up
15	1.656	.038	361.7	1.61
6	1.761	0.046	363.9	2.28
3	1.83	0.038	7	2.9
2	1.804	0.043	8	2.9

Result quality decreases slightly with fewer clusters

Floorplanner Speed up increases with fewer clusters

Related Work

- Temperature Estimation in Floorplanning
  - K. Skadron et al. in ISCA, Jun 2003.
  - K. Sankarnayanan et al. in Journal for ILP, 2006.
  - Single Power Profile: Average or Peak
- Application Dependent Floorplanning
  - C.-T. Chu et al. in IEEE ICCAD, Nov 2007
  - Single Power Profile: Average + Standard deviation

Conclusions

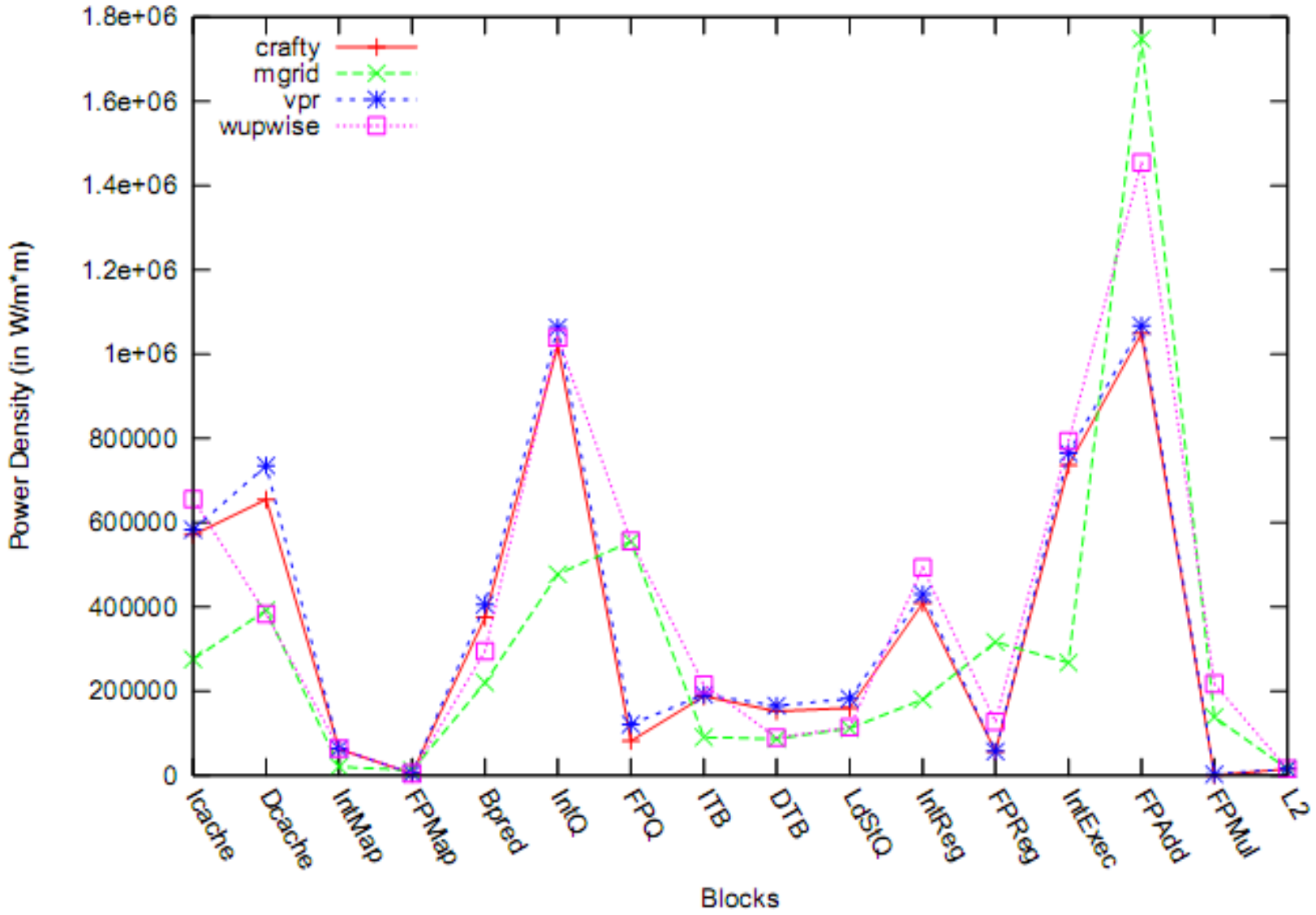
- In temperature estimation at micro-architecture level, average or peak power may give errors in estimation
- All uncorrelated power profiles should be considered during temperature estimation

Thank You

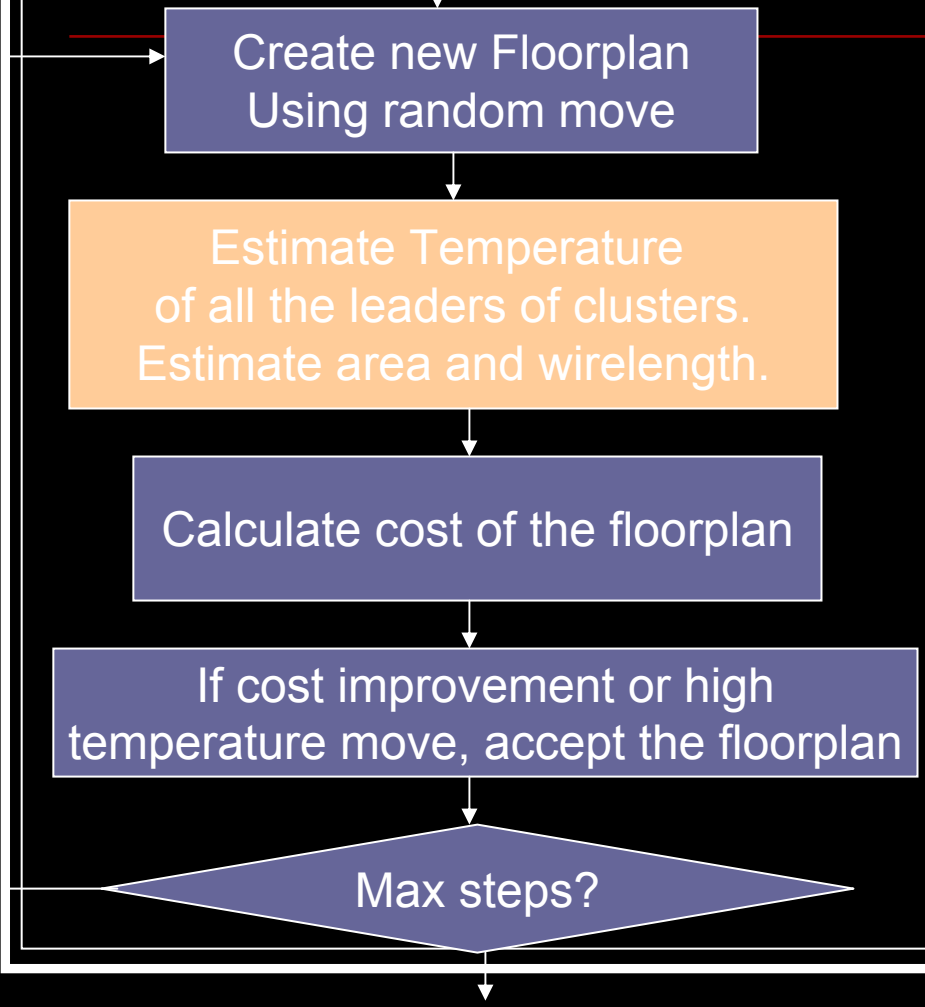
Multiple Applications in Temperature Estimation

- Temperature of a block depends on the power of neighboring blocks as well.
- Correlation of the power density of blocks is important
  - Application Specific
- Consider all applications to estimate peak temperatures
- Removes inaccuracy in temperature estimation
- Using all applications will slow the temperature estimation in floorplanning tool

Application Dependent Power Profile in Temperature Estimation



Thermal Aware Floorplanner



- Simulated Annealing based Floorplanner (HotFloorplan)
- Leakage Power is computed using temperature feedback loop and used for temperature estimation