Towards Fast and Accurate Parallel Chip Thermal Simulations with PACT

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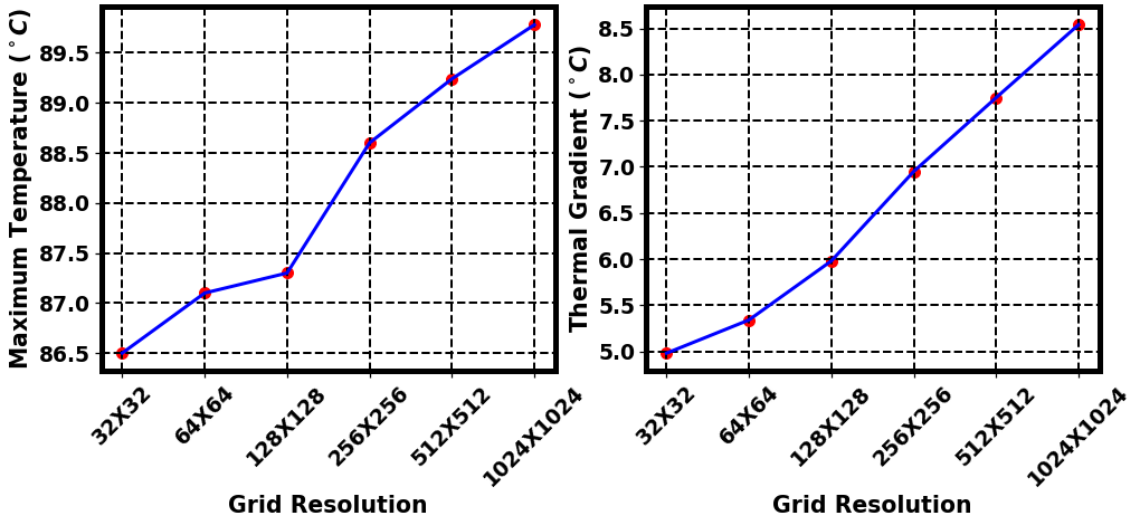
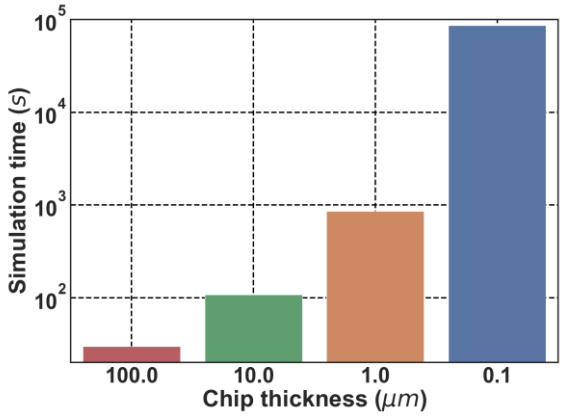
Workshop on Open-Source EDA Technology (WOSET)
October 6, 2021

Introduction and Motivation

- Challenges in existing compact thermal simulators
  - Target architecture-level thermal simulations
    - HotSpot [K. Skadron et al., ISCA'10]
    - 3D-ICE [A. Sridhar et al., ICCAD'10]
  - Cannot tackle large and complex problems
    - Standard-cell designs
    - Monolithic 3D simulations
  - Hard to extend emerging integration and cooling technologies
    - New models for cooling methods frequently roll out customized software package



[Z. Yuan et al., TCAD'21]



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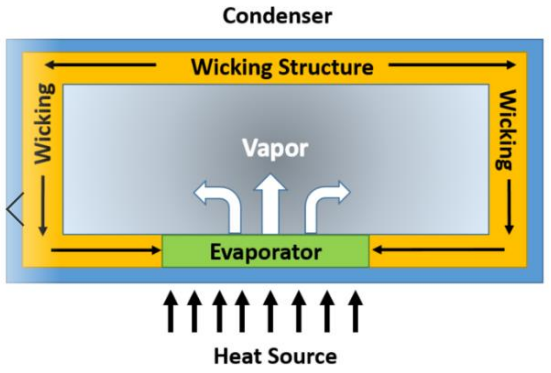


[Z. Yuan et al., ITherm'19]

Introduction of PACT

- Fast and accurate parallel thermal simulator (https://github.com/peaclab/PACT)
  - Supports both standard-cell level and architecture-level parallel thermal simulations
  - Enables (i) evaluating full real-world chips, (ii) fine-grained evaluations, and (iii) transient evaluations with realistic power profiles over longer time frames
  - Has high extensibility for emerging cooling solutions and technologies
  - Supports thermal evaluations of full industrial standard-cell designs from OpenROAD
  - Supports for various steady-state and transient solvers to speed up simulation time while maintaining the desired accuracy level
  - Integrates a transient thermal video generation tool, VisualPACT
- Validation against COMSOL
  - Max steady-state error: 2.77%
  - Max transient error: 3.28%

Overview of PACT

- PACT Simulation Flow
- Extensibility of PACT
- OpenROAD Interface and PACT Solvers
- VisualPACT

PACT Simulation Flow

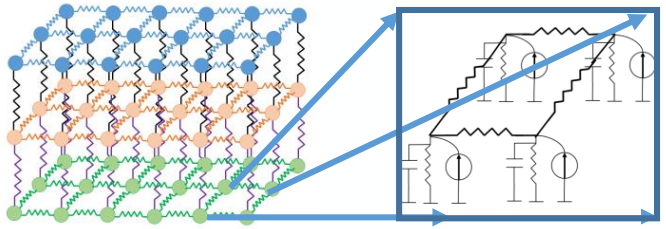
User inputs

- Chip stack descriptions (e.g., floorplan, # of layers, power traces)
- # of grids and heat sink type
- Material properties and cooling method

Calculate netlist components

- Calculate thermal R, C, and I
- Calculate package thermal R and C
- Calculate thermal R, C, and I for TSV and cooling methods

Thermal netlist generator



SPICE Engine

Outputs

- Runtime summary
- Resource usage summary
- Grid temperatures

Parallel configuration (OpenMPI)

- # of Node, # of Cores
- Parallel Option (e.g., -bind-to none)
- Job mapping option (e.g., -cpu-set)

Simulation type and solver selection

- Steady-state simulation (e.g., KLU, KSparse)
- Transient simulation (e.g., Backward Euler, Trapezoidal)
- Other simulation options (e.g., time period, step size)

Extensibility of PACT

Liquid cooling input parameters

```
[Liq]
Thermal resistivity ((m-k)/w) = 1.647
Specific heat capacity (j/m^3k) =
4.181e6
inlet_temperature (Celsius) = 27
fluid_density (kg/m3) = 998
dynamic_viscosity (pa.s) = 8.89e-4
coolant_velocity (m/s) = 0.5
num_of_channels = 2
```

Liquid.py

Liquid grid cell information

```
[Liq]
library_name = Liquid
library = Liquid.py
virtual_node = center_center
```

User inputs

- Chip stack descriptions (e.g., floorplan, # of layers, power traces)
- # of grids and heat sink type
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Calculate netlist components

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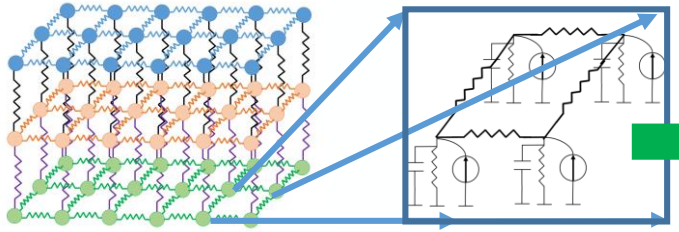
Thermal netlist generator



SPICE Engine

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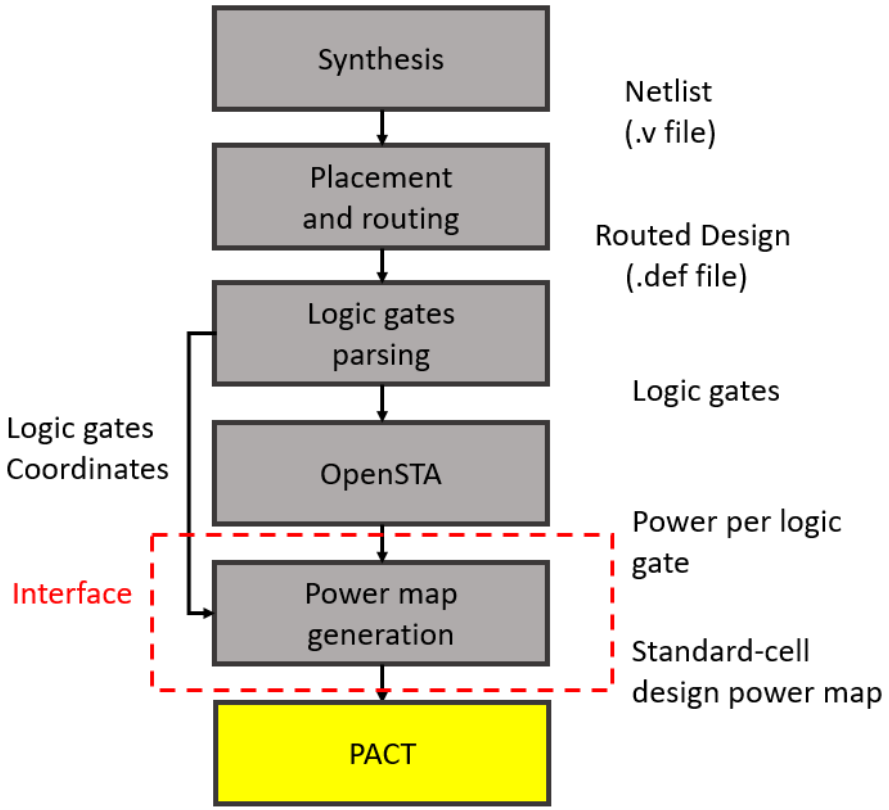
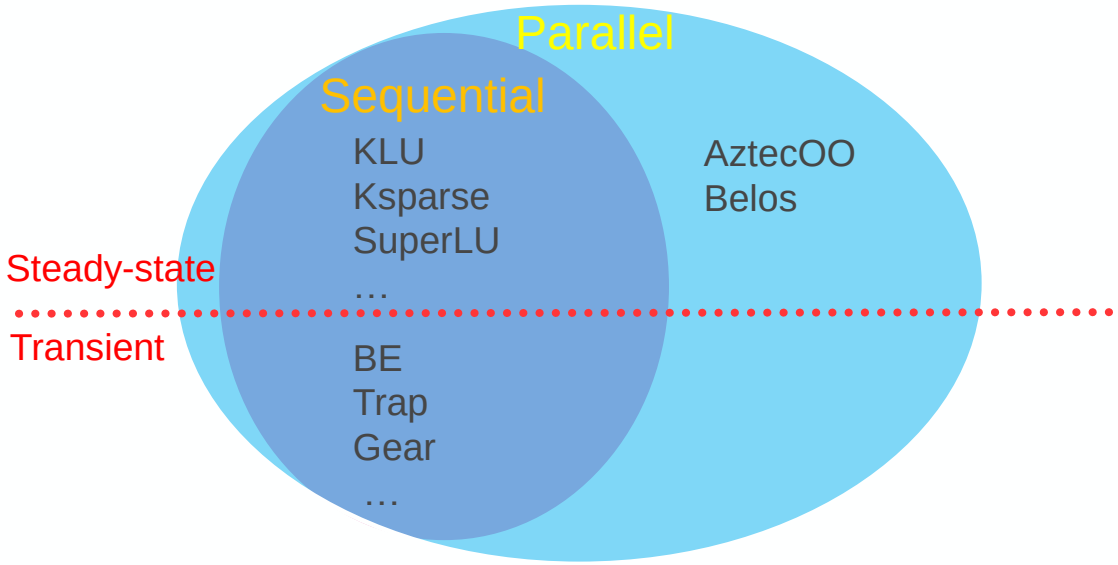
OpenROAD Interface and PACT Solvers

OpenROAD Interface



PACT Solvers

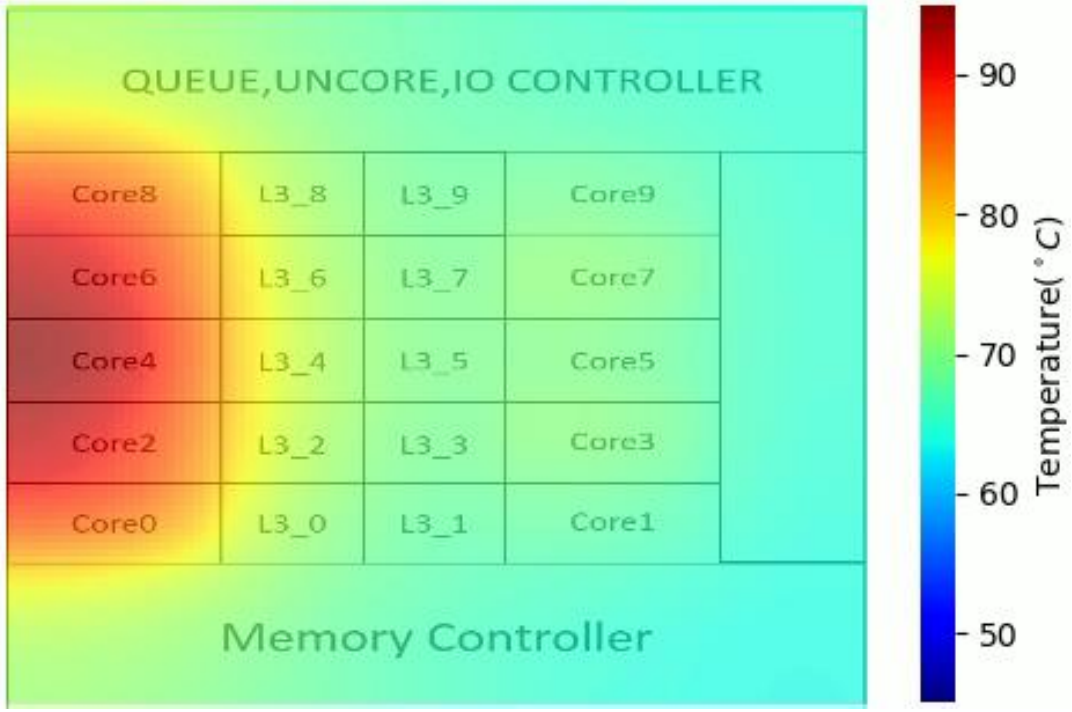
- Direct solver vs. Iterative solver
- Numerical instability issue with forward Euler method (Monolithic 3D transient simulation)
- Simulation speed and accuracy tradeoff



VisualPACT

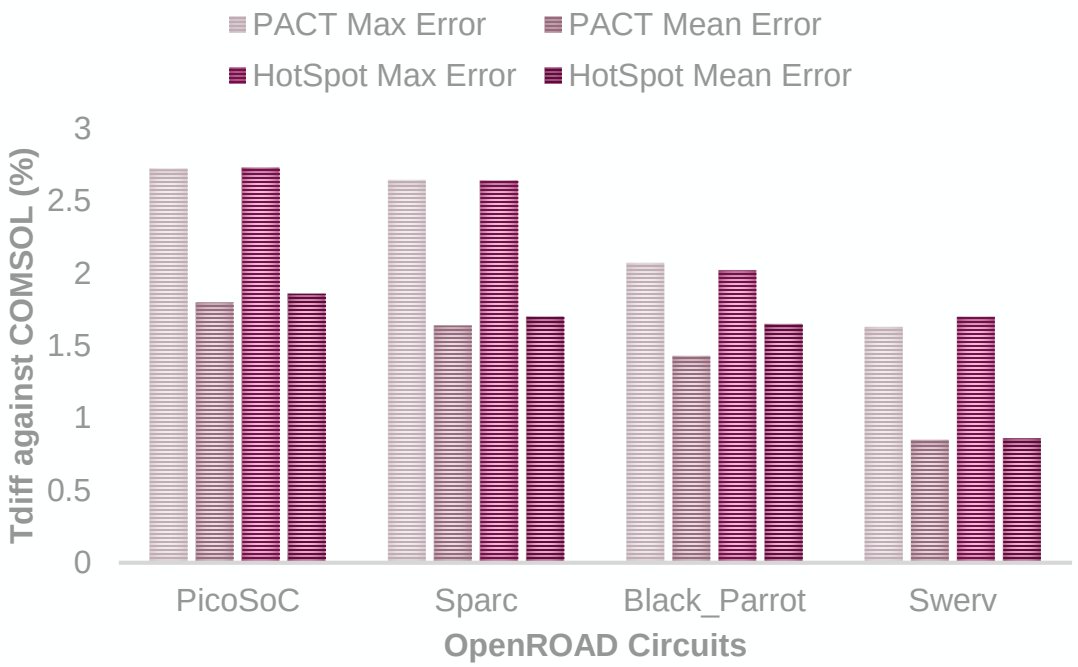
- PACT is compatible with architectural performance and power simulator
  - Sniper + McPAT + PACT
- VisualPACT
  - Generating thermal videos for transient thermal simulations
  - Visualizing transient thermal behaviors of architectural simulations
  - Sniper+McPAT+PACT+VisualPACT

VisualPACT Video (Intel i7 6950X)

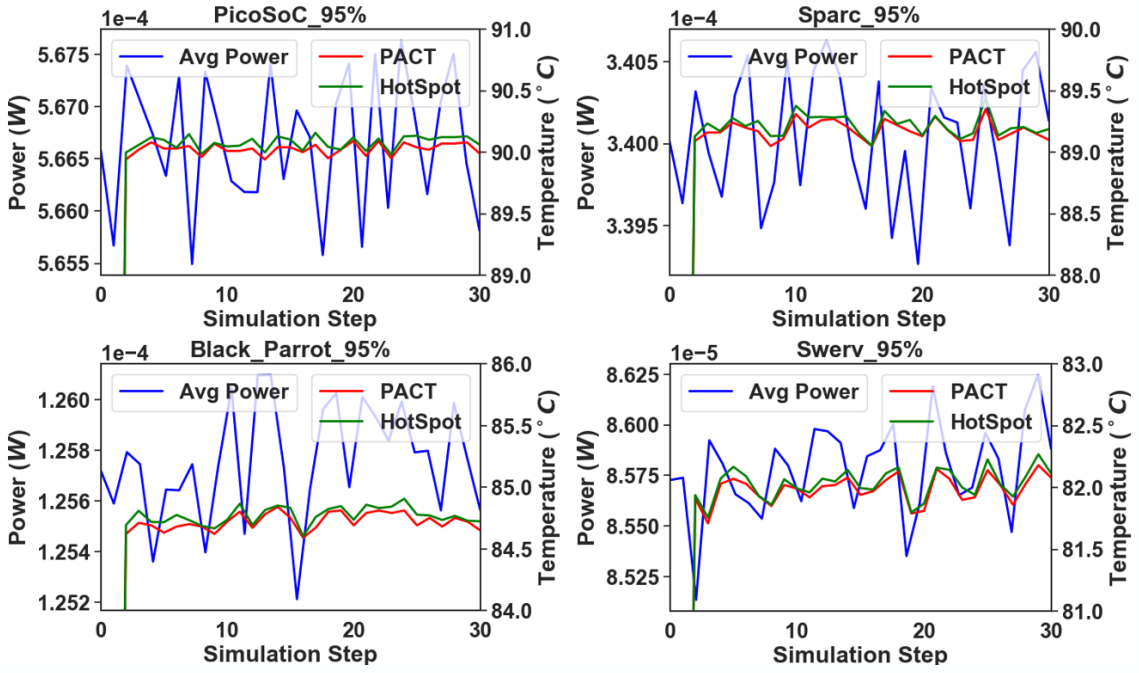


Validation with OpenROAD Benchmarks

Steady-State (Max Error: 2.77%)

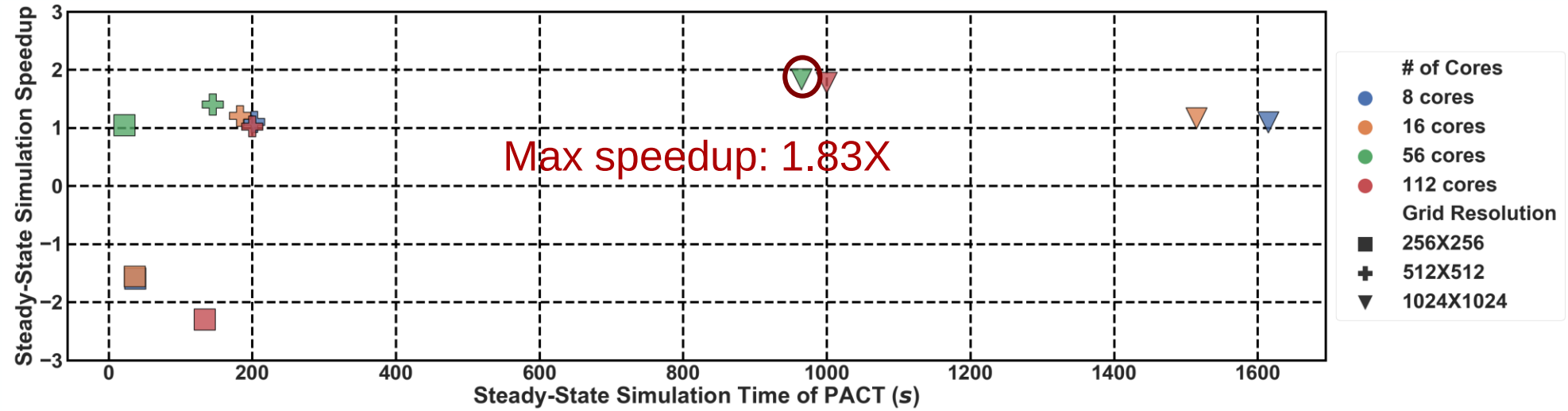


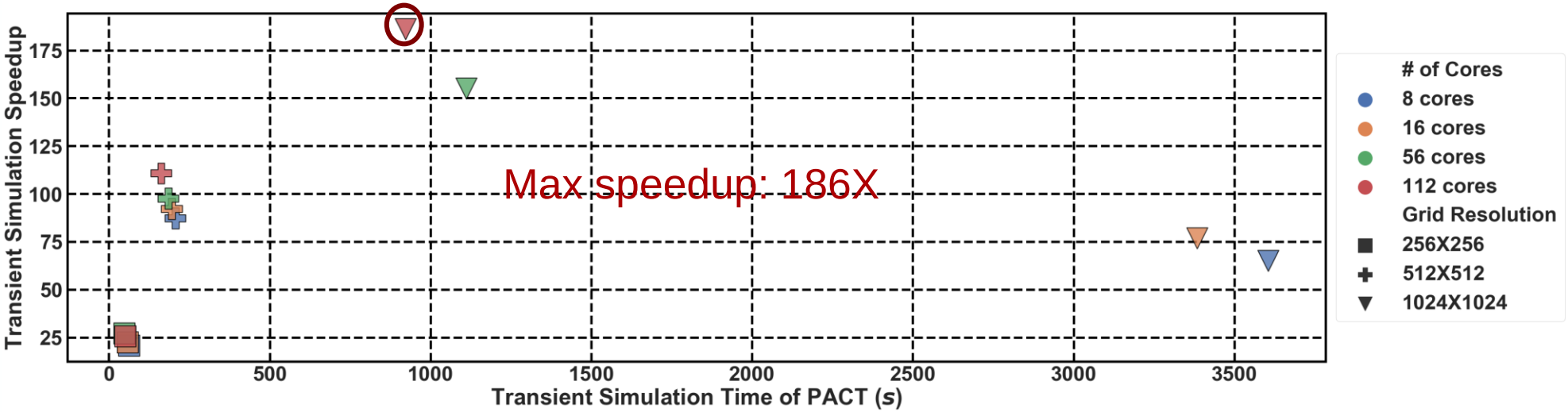
Transient (Max Error: 3.28%)



[Z. Yuan et al., TCAD'21]

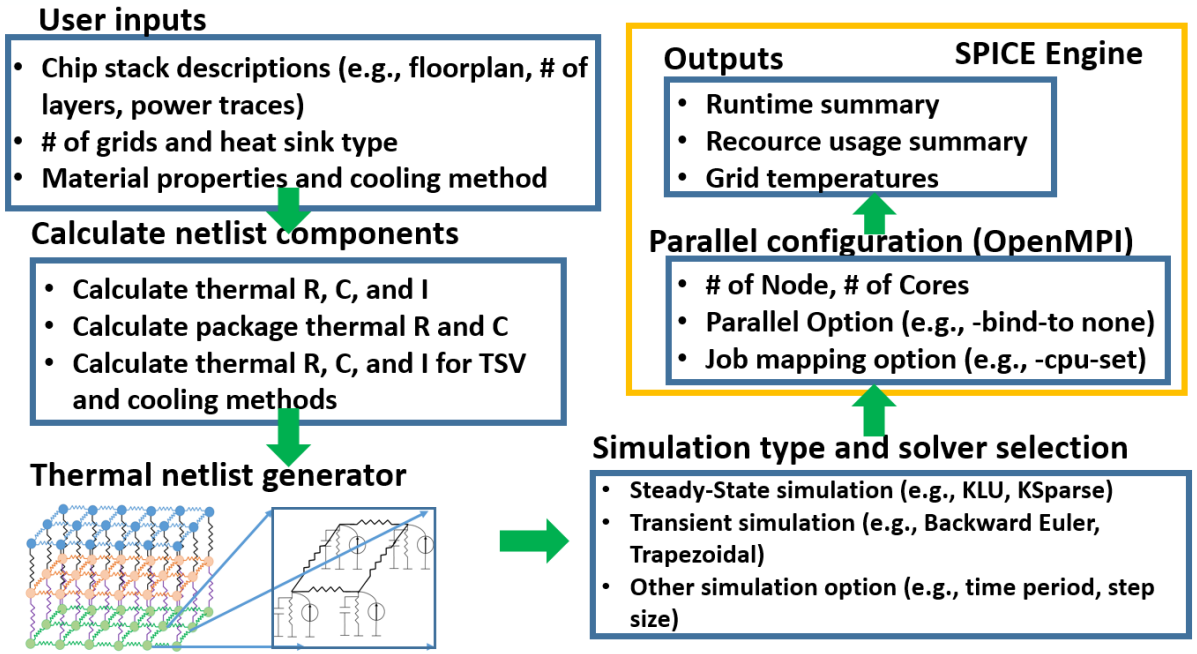
Speed Analysis with OpenROAD Benchmarks





[Z. Yuan et al., TCAD'21]

- PACT
  - Fast and accurate parallel thermal simulator
  - Architecture level & standard-cell level
  - High extensibility for emerging cooling methods
  - Various numerical solvers
  - OpenROAD interface
  - VisualPACT



Concluding Remarks

More info at https://github.com/peaclab/PACT

Please send feedback to yuan1z@bu.edu