Hybrid Analog-Digital Computing for Solving Nonlinear Systems

Yipeng Huang, Ning Guo, Mingoo Seok, Yannis Tsividis, Simha Sethumadhavan @ Columbia University

Motivation for analog in digital era

- Anticipated slowdown of speed and efficiency improvements in digital integrated circuits
- Analog circuits delivers fast and efficient computation with existing silicon technology
- Continuous-time, continuous-value hardware matches well with physical problems
- Downsides such as low precision and accuracy, limited scalability, and difficulty in programming can be mitigated
- Approximate solutions are useful in physical simulations and machine learning tasks

Broad applications in continuous math

- Time dependent PDE
  - Parabolic PDE (e.g., heat equation)
  - Elliptic PDE (e.g., Poisson eq.)
- Time independent PDE
  - Hyperbolic PDE (e.g., wave equation)
  - System of ordinary differential equations (ODEs)

Analog computer building blocks

- Integrator block
- Multiplier/VGA block
- Fanout block
- Nonlinear function block
- Adder/Subtractor block

Analog-digital programming toolchain

- Symbolic expression of equations
- Higher-level Compiler
  - Arduino IDE
  - C-style codes
- Lower-level Compiler
  - Machine codes
    - (16-bit Instruction Word)
    - (8-bit) Instruction Word
- Hybrid Computer API
- Computing block index (6 bits)
- + Block-level registers index (4 bits)
- + Register content (8 bits)

Mapping to physical hardware

- Partial differential equation (PDE)
  - Elliptic PDE
  - Parabolic PDE
  - Hyperbolic PDE
- Spatial discretization (e.g., finite difference)
- Linear (analog 20kHz projection)
- Linear (analog 80kHz projection)
- Linear (analog 320kHz projection)
- Linear (analog 1.3MHz projection)

Performance comparison

- Digital CG
- Analog 20kHz
- Linear (analog 20kHz projection)
- Linear (analog 80kHz projection)
- Linear (analog 320kHz projection)
- Linear (analog 1.3MHz projection)

Contact info & publications

yipeng@cs.columbia.edu
ng2364@columbia.edu
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