Why High-performance Computing?

(Lectures on High-performance Computing for Economists I)

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January 15, 2022

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Computation in economics I

- Computing has become a central tool in economics:

  1. Macro $\rightarrow$ solution and estimation of dynamic equilibrium models, policy evaluation and forecast, ...
  2. Micro $\rightarrow$ computation of games, labor/life-cycle models, models of industry dynamics, study of networks, bounded rationality and agent-based models, ...
  3. Econometrics $\rightarrow$ machine learning, non-standard estimators, simulation-based estimators, large datasets, ...
  4. International/spatial economics $\rightarrow$ models with heterogeneous firms and countries, dynamic models of international trade, spatial models, economic consequences of climate change and environmental policies, ...
  5. Finance $\rightarrow$ asset pricing, non-arbitrage conditions, VaR, ...
  6. Economic history $\rightarrow$ processing of large sets of non-standard information, library data, historical counterfactuals, ...

Computation in economics II

- Computation helps, complements, and extends economic and econometric theory. Judd (1997).
- Economics is not different from other scientific and engineering fields (if anything, economics has been slow to embrace computation).
- Widespread movement: *On Computing* by Paul S. Rosenbloom.
- Nowadays, computation in economics is also becoming key in:
    1. Policy making institutions.
    2. Regulatory agencies.
    3. Industry.

Past, present, and future

- Move towards computation started already in the 1950s (estimation of simultaneous equations models, simple static GE models, ...).
- But it gathered speed after the 1980s (RBC research program, first-generation simulation estimators, structural estimation, interest rate models, ...).
- Most likely, the computational trend will increase over time:
    1. Drop in computing costs.
    2. Big data.
    3. Machine learning and AI.
    4. New hardware.
    5. Change in composition of the profession.

Consequences for students

- This means that you will spend a substantial share of your professional career:
    1. Coding.
    2. Dealing with coauthors and research assistants that code.
    3. Reading and evaluating computational papers.
    4. Supervising/regulating people using computational methods.
- You want to lay solid foundations for future: concrete tools will change, fundamental ideas will not.

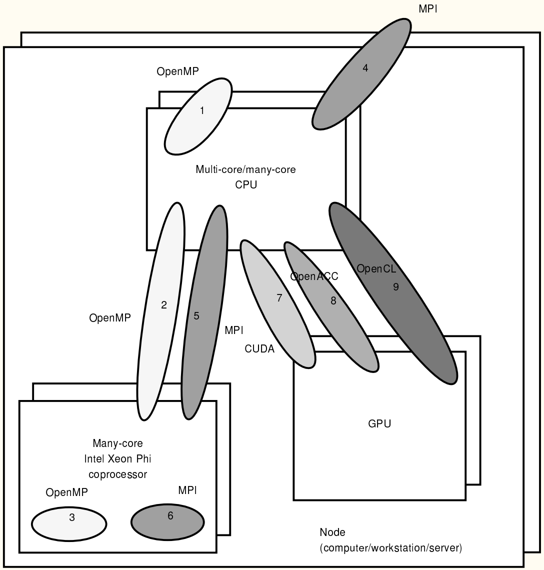
High-performance computing

- High-performance computing (HPC) deals with scientific problems that require substantial computational power.
- Even simple problems in economics generate HPC challenges:
    1. Dynamic programing with several state variables.
    2. Highly non-linear DSGE models with many shocks.
    3. Problems with occasionally binding constraints.
    4. Complex asset pricing.
    5. Structural estimation.
    6. Frontier estimators without close-forms formulae.
    7. Handling large datasets.

Parallel processing

- Usually, but not always, HPC involves the use of several processors:
    1. Multi-core/many-core CPUs (in a single machine or networked).
    2. Many-core coprocessors.
    3. GPUs (graphics processing units).
    4. TPUs (tensor processing units).
    5. FPGAs (field-programmable gate arrays).
- Most of these machines are available to all researchers at low prices.
- Nevertheless, we will also think about how to produce efficient serial code (although, following most recent developments, we will not emphasize much vectorization).

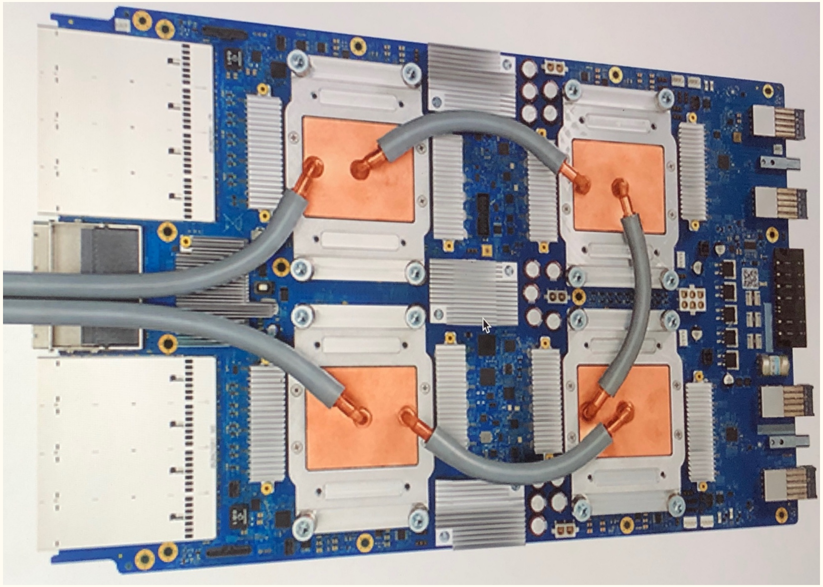
Parallel paradigms



GPUs

Coprocessor

TPUs



FPGAs

Total time

- Often HPC is framed regarding running time.
- In practice, coding and debugging time is likely to be more relevant than running time.
- We will spend considerable effort in discussing proper coding.
- Savings in development time are often first-order. Savings in running time are most times second-order.

Adapted from Gen. Robert H. Barrow, USMC (27th Commandant of the US Marine Corps)

Amateurs talk about the speed of their processors, but professionals study coding techniques.

Some resources

- HPC carpentry: `https://hpc-carpentry.github.io/`.
- Victor Eijkhout's homepage: `http://pages.tacc.utexas.edu/~eijkhout/istc/istc.html`.
- Livermore documentation and tutorials: `https://hpc.llnl.gov/training/`.
- HPC Wire: `https://www.hpcwire.com/`.
- Inside HPC: `https://insidehpc.com/`.
- *Introduction to High Performance Computing for Scientists and Engineers* by Georg Hager and Gerhard Wellein.
- *Parallel and High Performance Computing* by Robert Robey and Yuliana Zamora.
- *High Performance Computing: Modern Systems and Practices* by Thomas Sterling, Matthew Anderson, and Maciej Brodowicz.

Other material

- This set of notes does NOT cover:

    1. Theory of computation and complexity theory.
    2. Automata theory.
    3. Computer architecture.
    4. Computer arithmetic.
    5. Numerical analysis.
    6. Solution, estimation, and parallelization algorithms applied to economics.
    7. LaTeXand BibTeX.