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A Simple Cost-model for Comparing Diverse Architectures

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How to Compare Diverse Hardware?

Diverse hardware has wide-ranging costs and benefits.

- NVIDIA A100 costs more than RTX but is "faster"
- A100 costs more than Intel Platinum but is "faster"
- Is the extra cost worth it? Depends on workload and how fast you need the results (*result depreciation*).

How to compare Costs vs Benefits of hardware choices?

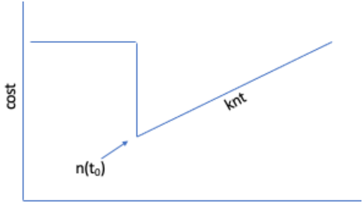
- Capture costs in Total Cost to Own (TCO) architecture i per unit time as κ_i
  - Depreciation of hardware or Cloud Provider charges per hardware device
  - Power and cooling cost per device
  - Other costs that increase with device count
- Benefits
  - Reduced result depreciation (more productivity/throughput, e.g. less time to science)

Cost Model: Cost of a Run

Find minimum cost hardware for a **run**

- run = figure of merit for an application (one iteration, ns, time-to-solution)
  - *cost-per-run* $= c$ [\$]
- $\kappa_i =$ holistic TCO of 1 device of architecture i per unit time
- assume portion of workload benefits from parallelization
  - $t_i = t_{i,s} + t_{i,p}/n_i$ (measure $t_{i,s}$, $t_{i,p}$ in a scaling study)
  - $c_i = \kappa_i n_i t_i = \kappa_i (n_i t_{i,s} + t_{i,p})$
  - $t_{i,s}$, $t_{i,p}$ are fixed for a given architecture and workload $\rightarrow$ c_i strictly increasing with n_i
- $n_i = 1$ is always c_{min} ("always" a serial component)
- Minimizing cost-per-run maximizes runs/$ (throughput) !!!

Cost Model: Strict Performance Requirements



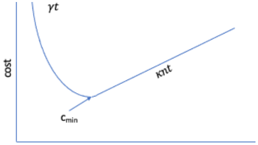
Most cost effective architecture *i* is straightforward with rigid requirements

- Big cost penalty for not completing run in time t_0
- $c_i = \kappa_i n_i t_i = \kappa_i(n_i t_{i,s} + t_{i,p})$ were $t_i \leq t_0$ is required
- If serial workload then $n_i = 1$ and $c_{min} = min(\{\kappa_i t_{i,s}\})$
- if parallel workload then $n_i = \frac{t_{i,p}}{t_0 - t_{i,s}}$ and $c_{min} = min(\{\kappa_i \frac{t_{i,p} t_0}{t_0 - t_{i,s}}\})$
  - Memory footprint requirements work similarly

Cost Model: Relaxed Performance Requirements

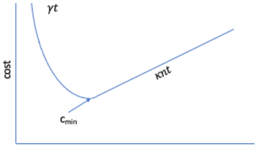
Relax performance requirements but account for depreciation of the run result

- If no penalty for longer runtime than always run serially ($n_i = 1$)
- Computational result is worth less in the future than it is *now*
  - value of computational results depreciate over time
- Assume linear depreciation of result with time: $V(t) = V_0 - \frac{V_0}{T} t = V_0 - \gamma t$



  - $c_i(n_i) = \underbrace{\kappa_i n_i t_i(n_i)}_{compute\ cost} + \underbrace{\gamma t_i(n_i)}_{result\ depreciation}$
- *result depreciation* difficult to quantify but lower runtime *is* valued
- *compute cost* is off-set by *result depreciation*

Cost Model: Minimize $c_i = \kappa_i n_i t_i + \gamma t_i$



Minimize cost-per-run of architecture i: c_i

- $dc_i/dn_i = 0$
  - $n_i = \sqrt{\frac{\gamma t_{p,i}}{\kappa_i t_{s,i}}}$ (cost-optimal number of devices to use)
- c_{min} for architecture i
  - $c_{min,i} = \left(\sqrt{\gamma t_{s,i}} + \sqrt{\kappa_i t_{p,i}}\right)^2$
- $c_{min} = min(\{c_{min,i}\})$

Cost Model: Estimating γ?

What is the depreciation rate (γ) of a run's result?

- If γ and fraction of work parallelizable are equal for each architecture then *relative* costs are independent of γ
  - Choose the cheapest
- Run results correlate to R&D output or revenue
  - images recognized, search results returned, bitcoin mined, ns simulated etc.
- If related to revenue γ may be straightforward to estimate
  - lost asset appreciation (e.g. invest V_0 now and make γt interest on a loan)
  - drug revenue per unit time
- If related to pure γ R&D (e.g. TACC) probably more abstract
  - Assume R&D value is as valuable as the HPC infrastructure that supports it.
  - Include any cost that doesn't increase with device count
    - total system budget
    - cost to port to new architecture (γ_i), licenses

Summary

Demonstration of Cost-model to Optimize a System Procurement

*Evans R.T. et al. (2021) Optimizing GPU-Enhanced HPC System and Cloud Procurements for Scientific Workloads. In: Chamberlain B.L., Varbanescu AL., Ltaief H., Luszczek P. (eds) High Performance Computing. ISC High Performance 2021. Lecture Notes in Computer Science, vol 12728. Springer, Cham.

Many Uncertainties

- Amdahl's law approximations introduce uncertainties. We do know c_{min}
  - not in super-linear scaling regime
  - not in regime where scaling fails
  - can add terms to t_i (e.g. $log(n_i)$) and solve transcendental for n_i
- Defining proxy workload
- Depreciation not necessarily linear
- Estimating TCO - κ_i - precisely is exhausting
  - Difficult to measure: Can be quite difficult if taking code porting into account
- γ can be tricky - consider lost revenue or cost of system

Thank you

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