Design of Experiments

CS/ECE 541

Performance Analysis

- Performance of a system affected by multiple factors
  - CPU, Disk, Network card, packet sizes
- Each factor may have multiple levels, e.g.
  - 3 types of CPUS (single core, dual core, multi-core)
  - L1 cache size (1Gb, 4Gb, 8Gb)
  - Disk speeds (4800 rpm, 5200 rpm, 7200 rpm, 10000 rpm)
  - Network sizes (10 Mbps, 100 Mbps, 1 Gbps, 10 Gbps)
  - Packet sizes (64B, 1Kb, 4Kb)
  - Program size (1Mb, 100Mb, 1Gb)
- If we want "average performance" where the average is over all factor levels we have lots of combinations to consider, above

$$3 \times 3 \times 4 \times 4 \times 3 \times 3 = 1302$$

Experimental Design

- Design a proper set of experiments for simulation, don't do all possible combinations
- Develop a model that best describes data
- Estimate the contribution of each factor to the metric(s) of interest
  - To which factors (or combination of factors) is performance most sensitive?
  - Understanding the model, not just predicting response
- Isolate measurement errors
- Check whether model is adequate

Terminology

- Factor : variable that affects response variable
  - E.g. from before, CPU, L1 cache size, etc.
  - Sometimes called *predictor variables*
- Level : values that a factor can assume
- Replication: repetition of all or some experiments
- Design: The number of experiments, the factors used, and the number of replications @ experiment
- Full Factorial Design : all combinations
- Interaction
  - Sometimes system performance depends a lot on the relationship between a couple of factors

Common Mistakes

- Variation due to experimental error is ignored
- Parameters that are important to performance are not controlled.
- Effects of different factors are not isolated
- Simple “one-factor-at-a-time” designs are used
- Interactions are ignored
- Too many experiments, no thought to what is done or how to analyze it

One factor at a time

Choose a point in factor space $(f_1, f_2, f_3, f_4, f_5)$

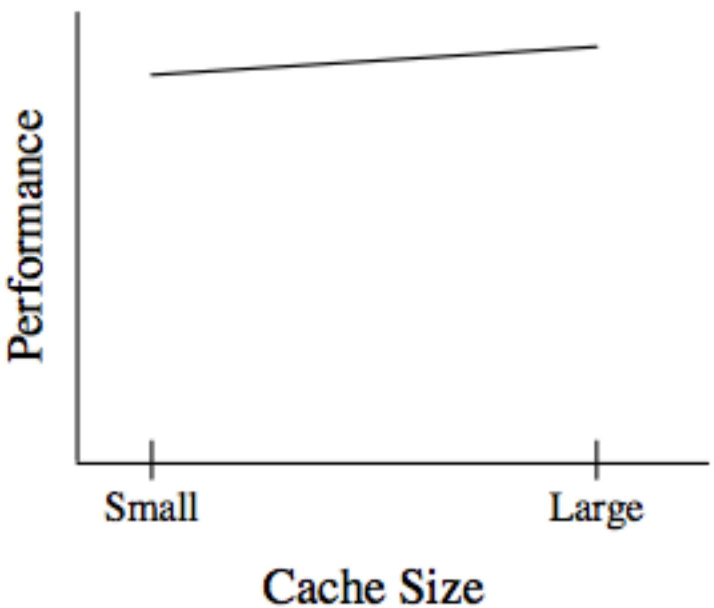
$\forall\ i$ Fix all $j \neq i$, vary f_i

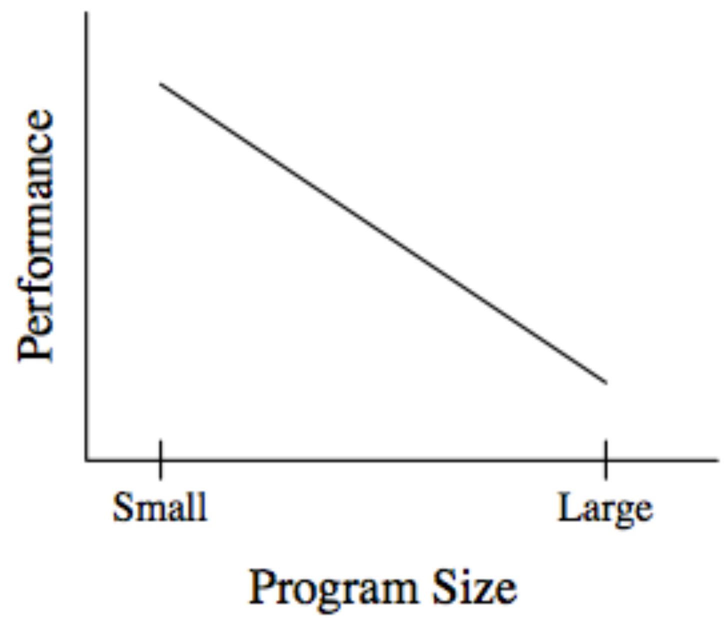
Problem---what about system behavior elsewhere in factor space???

One factor at a time

When nominal levels of are all “low” and you study cache size and program size you might get this

- insensitivity to cache size, decreasing performance in program size



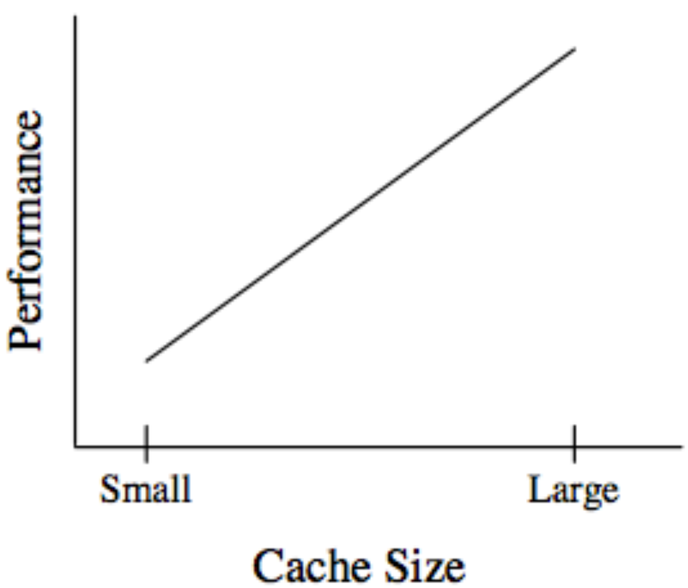


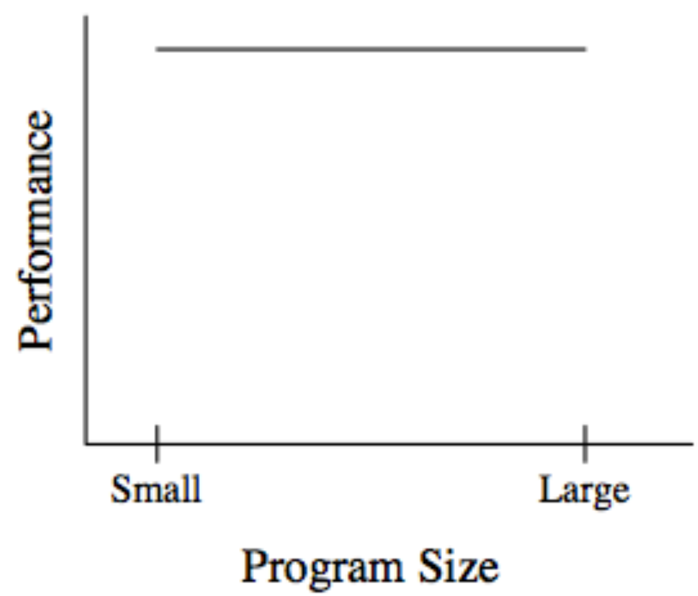
One factor at a time

When nominal levels of are all “high” and you study cache size and program size you might get this

- increasing in cache size, insensitive to program size

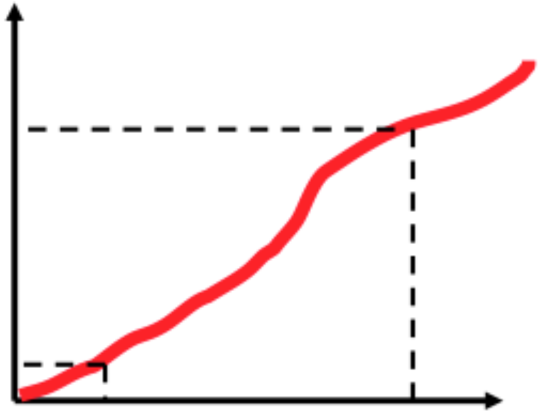
One factor at a time misses any “overall” tendency or sensitivity to factor levels

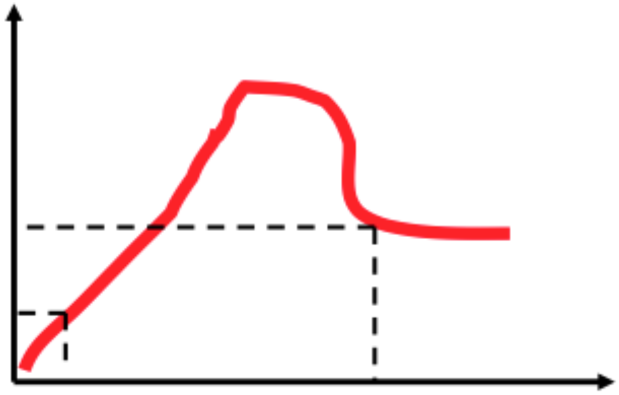




2^k Factorial Design

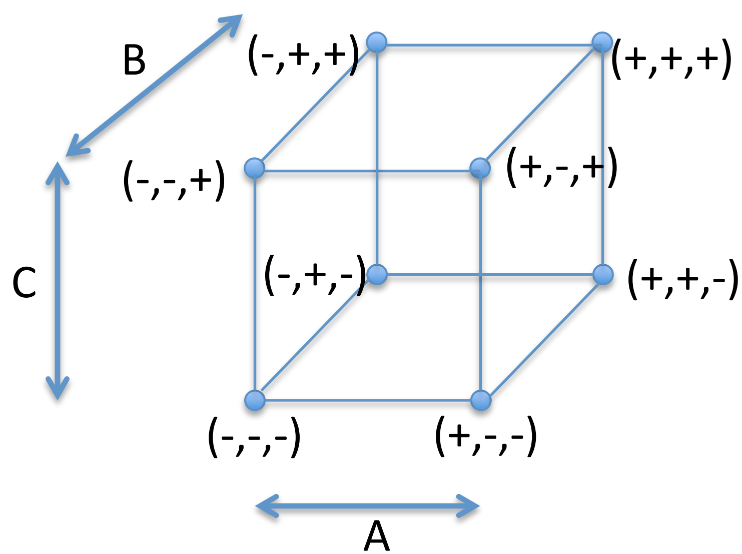
- k factors, two each level (typically “high” and “low”)
- Easy to analyze
- Helps separate impact of factors
- Good at the beginning of a study
- But valid only if the effect of each factor is monotone over the two levels





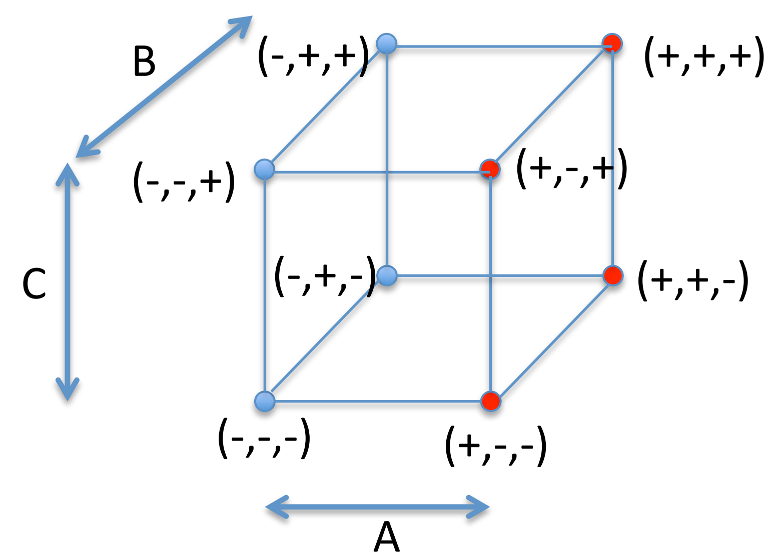
Some notation

- For each factor we can denote the larger level by ‘+’ and the smaller level by ‘-’
- We can think of the combinations as forming a hypercube, with experiments that differ in only one factor being adjacent



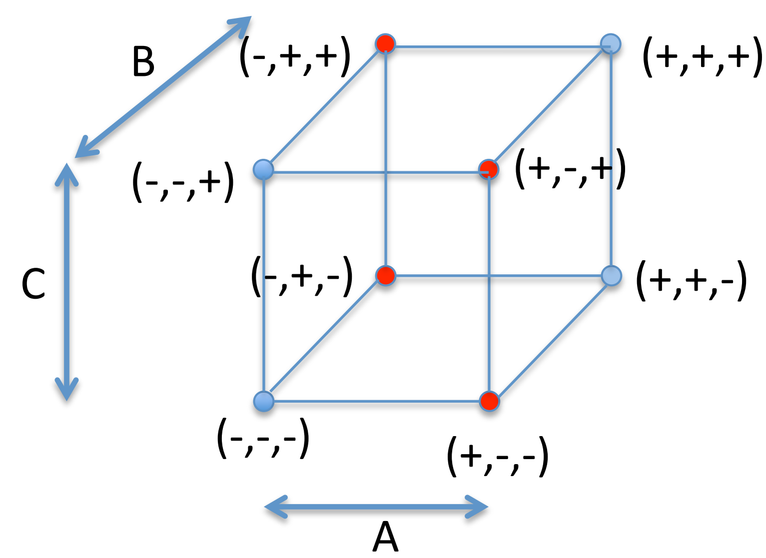
Effect of one factor

- Average all the measurements where the factor is ‘high’, call it X_high
- Average all the measurements where the factor is ‘low’, call it X_low
- Compute X_high – X_low
- What’s this mean?



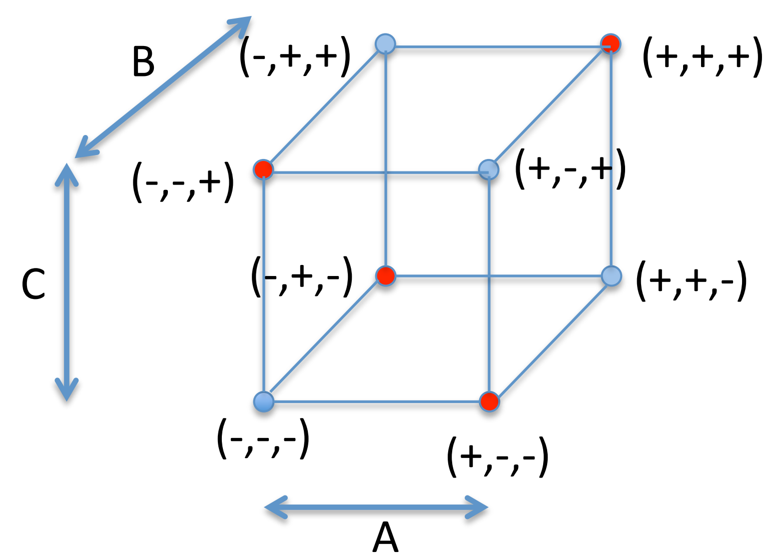
Effect of two factors

- Average all the measurements where both factors are both ‘high’ or both ‘low’ (call it A_same)
- Average all the measurements where one factor is ‘high’ and the other is ‘low’ (call it A_diff)
- Compute X_same – X_diff
  - Identifies sensitivity to factors swinging the same direction
- Example: AB



Effect of j particular factors

- Average all the measurements where number of factors levels that are 'high' is even
- Average all the measurements where number of factor levels that are 'high' is odd
- Compute X_same – X_diff
  - Identifies sensitivity to factors swinging the same "direction"
- Example: ABC



Eyeballing factor contribution

Make a table that lists effect estimation, e.g.

Effect	Effect Estimate
A	3.0
B	1.5
C	0.5
AB	1.0
AC	0.0
BC	-0.5
ABC	0.0

Effect *magnitude* is the important thing to look for

In the above, factor A and factor B are the most significant