General Measures from HPC Area with potential Relevance to TripCom

- **Execution time** is basic and most important parameter in HPC
  - other measures based on execution time
- T_n ... execution time of a program on n nodes
- **Speedup** measures parallel execution time relative to sequential execution time
- $speedup(n) := T_1 / T_n$
  - ideal $speedup(n) = n$
  - *superlinear speedup possible: cache usage, thread scheduling, ...*
  - also termed *strong* scalability
- **Efficiency**: speedup per node
- $efficiency(n) := speedup(n) / n$, ideally 1

Scalability Measures

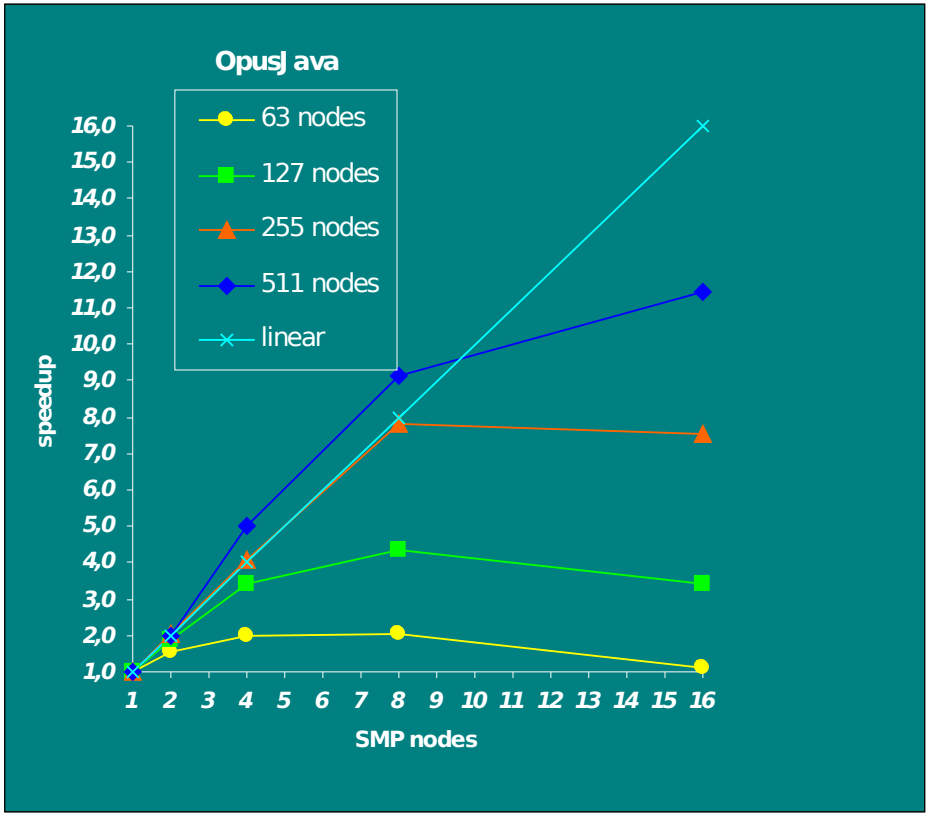
- Considering “problem size”
  - memory used, data size
  - more general: computational work, number of worker tasks
- T_n^N ... execution time for solving problem of size N on n nodes
- What is the effect of increasing problem size?
- ***growth_factor***$(k) := T_n^{k*N} / T_n^N$
  - $n=1$: sequential growth
  - n>1: parallel growth

Scalability Measures

- What is the effect of simultanously increasing (e.g., doubling) problem size N and number of nodes n?
  - increase of n compensates for increase of N?
- ***scalability_factor***$(k) := T_n^N / T_{k*n}^{k*N}$
  - ideal $scalability\_factor(k) = 1$
  - 0.8 is quite good
  - also termed *weak* scalability
- How does increase of problem size influence speedup ?
- ***robustness***$(n) := T_1^N / T_n^N$
  - fixed relation $N/n=c$
  - $e.\ g.\ (c=64),\ T_1^{128} / T_2^{128},\ T_1^{256} / T_4^{256},\ T_1^{512} / T_8^{512},\ \ldots$

Example: Stochastic Optimization

Tree Nodes	Compute Nodes	Execution Time	Speedup Robustness	Scalability
63	1	742,00	**1,00**	**1**
63	2	476,00	1,56	
63	4	375,00	1,98	
63	8	359,00	2,07	
63	16	664,00	1,12	
127	1	2302,00	1,00	
127	2	1211,00	**1,90**	**0,61271676**
127	4	671,00	3,43	
127	8	532,00	4,33	
127	16	673,00	3,42	
255	1	6658,00	1,00	
255	2	3267,00	2,04	
255	4	1623,00	**4,10**	**0,45717807**
255	8	854,00	7,80	
255	16	885,00	7,52	
511	1	18099,00	1,00	
511	2	9182,00	1,97	
511	4	3596,00	5,03	
511	8	1979,00	**9,15**	**0,37493684**
511	16	1584,00	11,43	



Scalability Measures

- *Memory constrained* scaling
  - keep amount of memory used per processor constant
- Vs. ***time constrained*** scaling
  - keep total execution time constant, assuming perfect speedup
- $T_{k*n}^{x} = T_{n}^{N}$ *(1)*
  - how large is the scaled problem size x ?
  - requires time $T_{n}^{N}(N)$ to be known
  - e.g., $T_{n}^{N} = N^{2}$
- choose *x* s.t. $T_{n}^{x} = k* T_{n}^{N}$ *(2)*
  - *e.g.,* $x^{2} = k\,N^{2}$, $x = sqrt(k)*N$
- perfect speedup: $T_{k*n}^{N} = T_{n}^{N} / k$ *(3)*
  - $k*T_{k*n}^{N} =^{(3)} k*T_{n}^{N} / k =^{(2)} T_{n}^{x} / k =^{(3)} T_{k*n}^{x} = T_{n}^{N}$

Scalability Measures

- Measures not based on execution time may also be important in HPC
- Can provide insight into reasons for bad performance and potential performance losses
- **Work distribution**
- **Communication**
  - number of data transfers
  - amount of data transferred
- **Computation/communication ratio**
- **Cache misses**
- **…**

Scalability techniques in HPC

- Scalability is (implicit) goal of performance optimization
- Minimize sequential code portions
  - cf. Amdahl's law: *speedup(n) = 1 / ((1-f)+f/n)*
  - *f ...* parallel code portion
  - e.g., *speedup(100)=80 => 1-f = 0.25%*
  - *e.g., 1-f = 20% => maximal speedup = 5*
- Minimize communication
  - i.e., minimize communication/computation *ratio*
- Communication latency *hiding*
  - $comm\_time = c_0 + c_1 * data\_volume$

Scalability techniques in HPC

- Communication/computation *overlapping*
- Workload balancing: keep processors busy
- Granularity tradeoff
  - small granularity, high degree of parallelism, lot of communication
  - larger granularity, lower degree of parallelism, less communication
- Asynchronous communication
  - asynchronous algorithms
- Remove data dependencies
  - by transforming the sequential code
    - manually, (semi-)automatic

Data Locality

- For distributed memory systems, scalability is strongly determined by the degree of data locality
- *Data parallel programming*
  - partitioning of data domain
  - every processor executes the same program, but on different data („owner computes“-rule)
  - SPMD: Single Program Multiple Data
- *Data distribution* determines *work distribution*
  - can be derived by a parallelizing compiler
  - sequential program is annotated by *data distribution directives*

Open Issues

- Adaptation of HPC experiences to the TripCom scalability issue
- What can be re-used
- What must be modified
- …