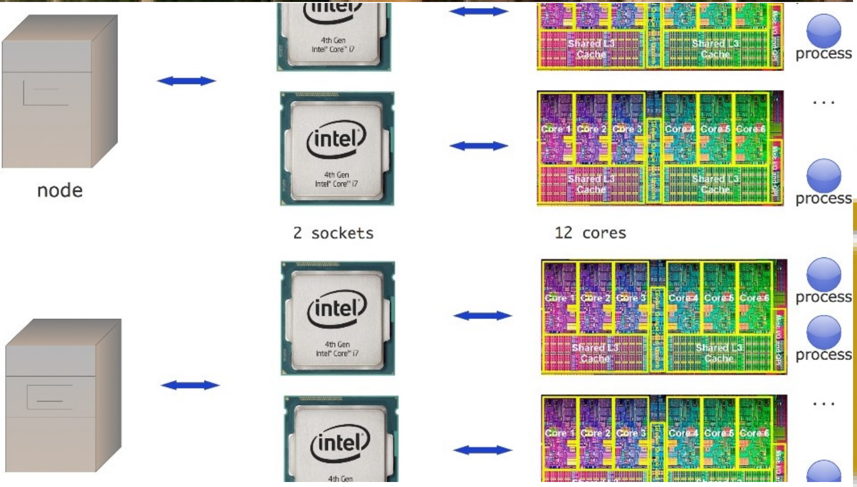
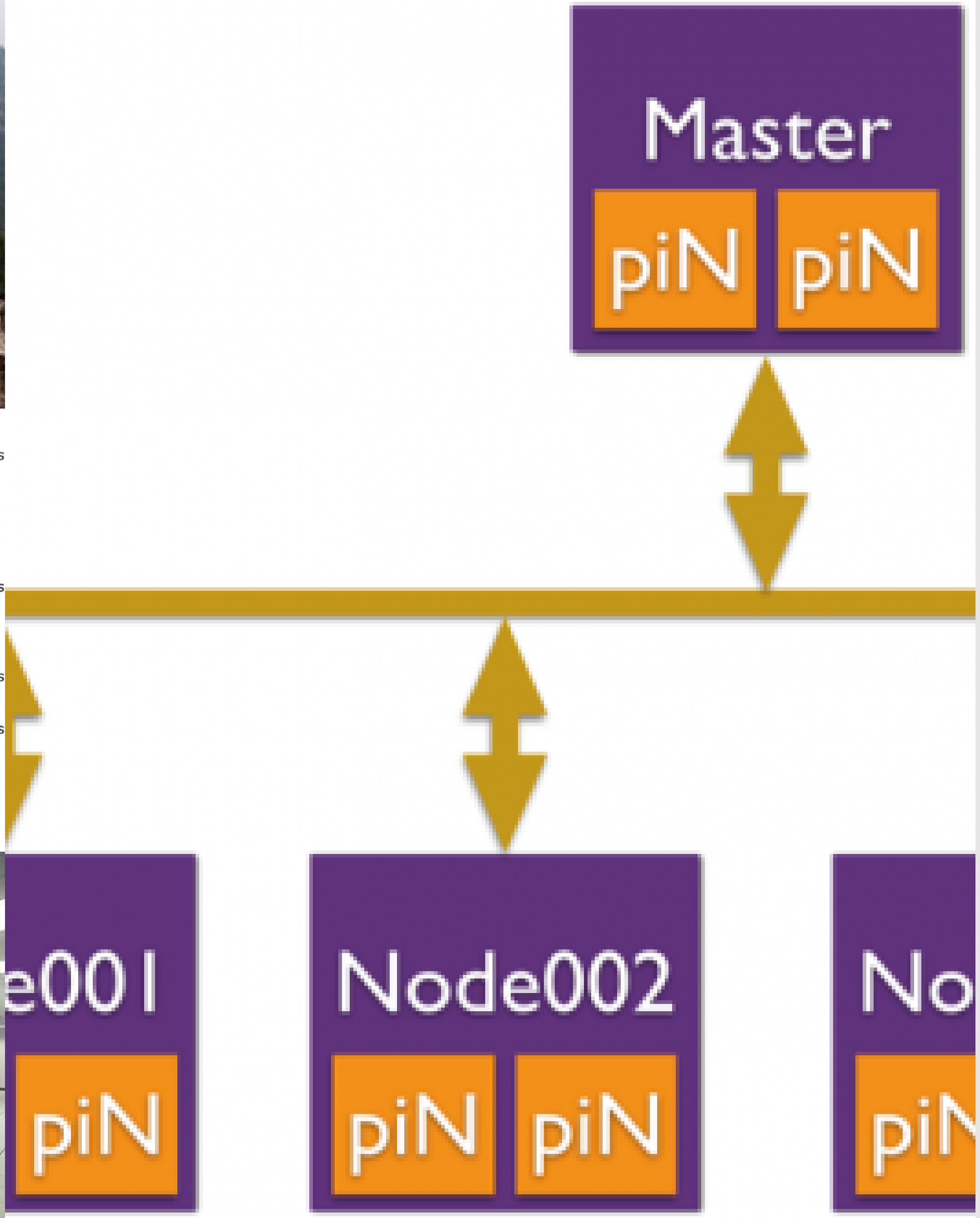
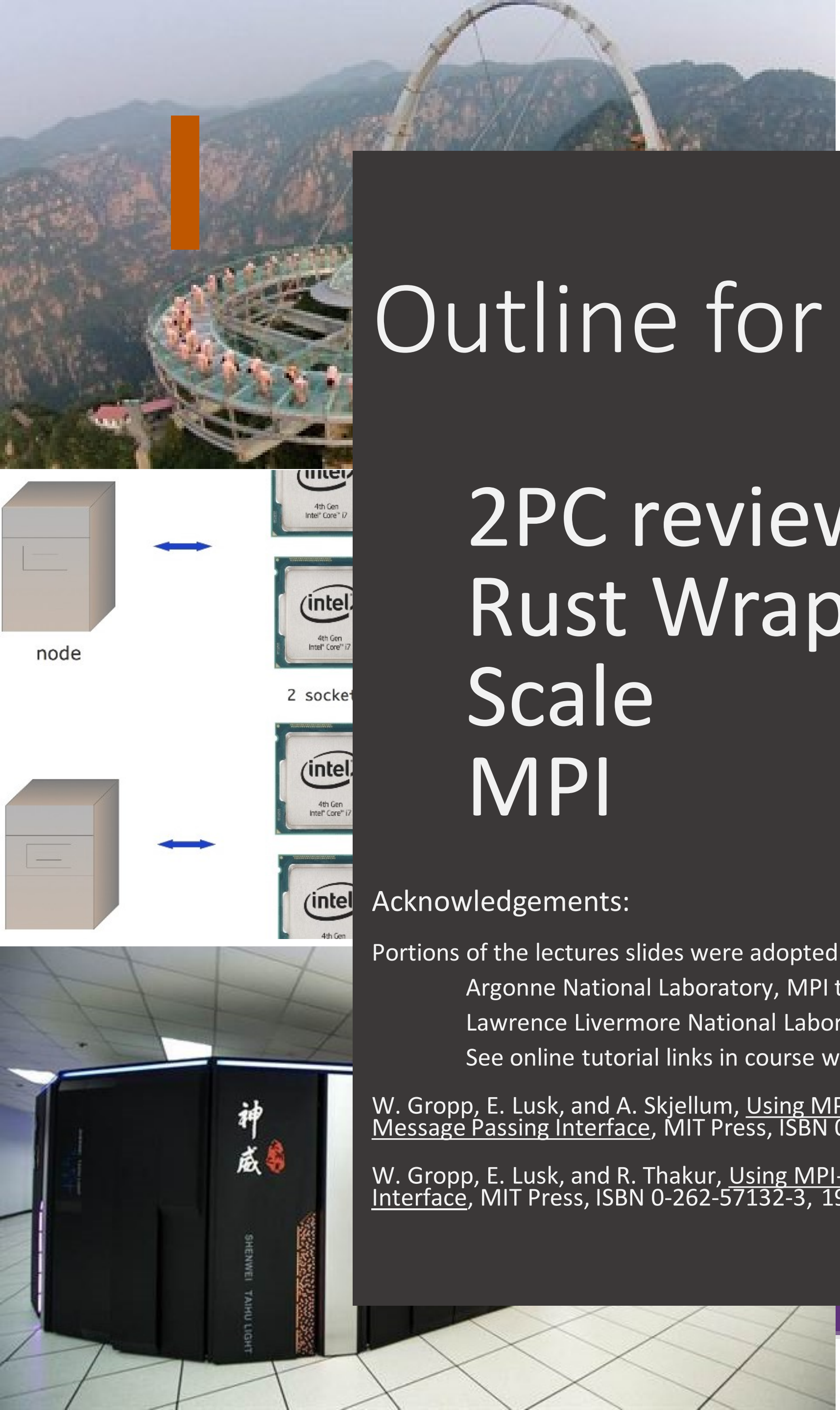
Parallelism at Scale: MPI

cs378h


node
2 sockets
12 cores
process
process
process
process


神威


Master
piN
piN
Node002
piN
piN
piN



Outline for Today

- 2PC review
- Rust Wrapup
- Scale
- MPI

Acknowledgements:

Portions of the lectures slides were adopted from:

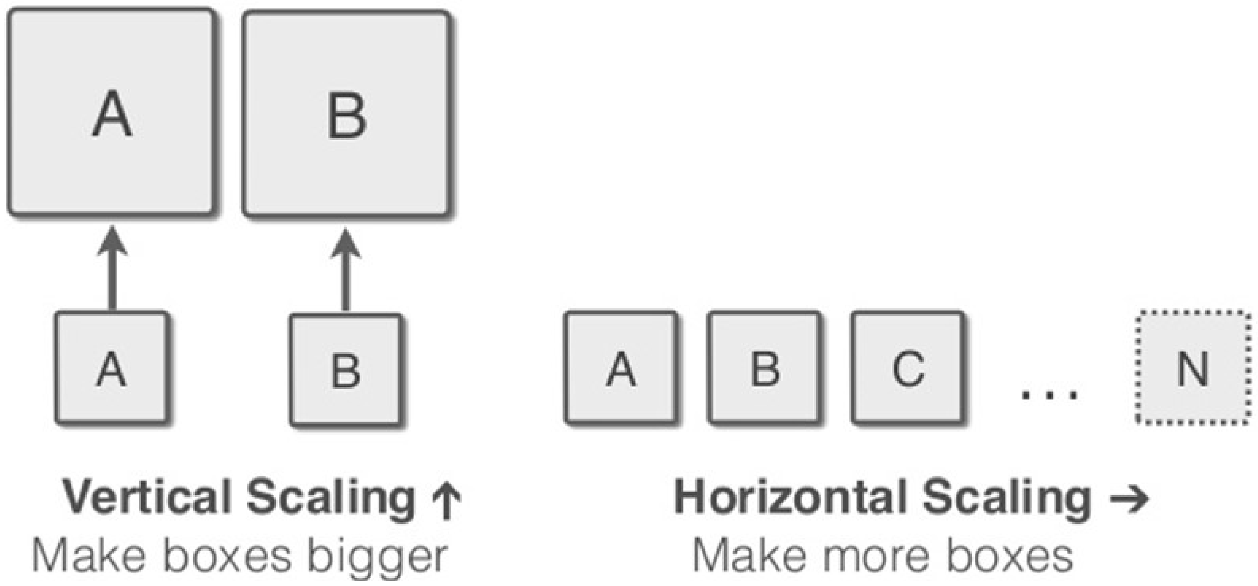
- Argonne National Laboratory, MPI tutorials.
- Lawrence Livermore National Laboratory, MPI tutorials
- See online tutorial links in course webpage

W. Gropp, E. Lusk, and A. Skjellum, Using MPI: Portable Parallel Programming with the Message Passing Interface, MIT Press, ISBN 0-262-57133-1, 1999.

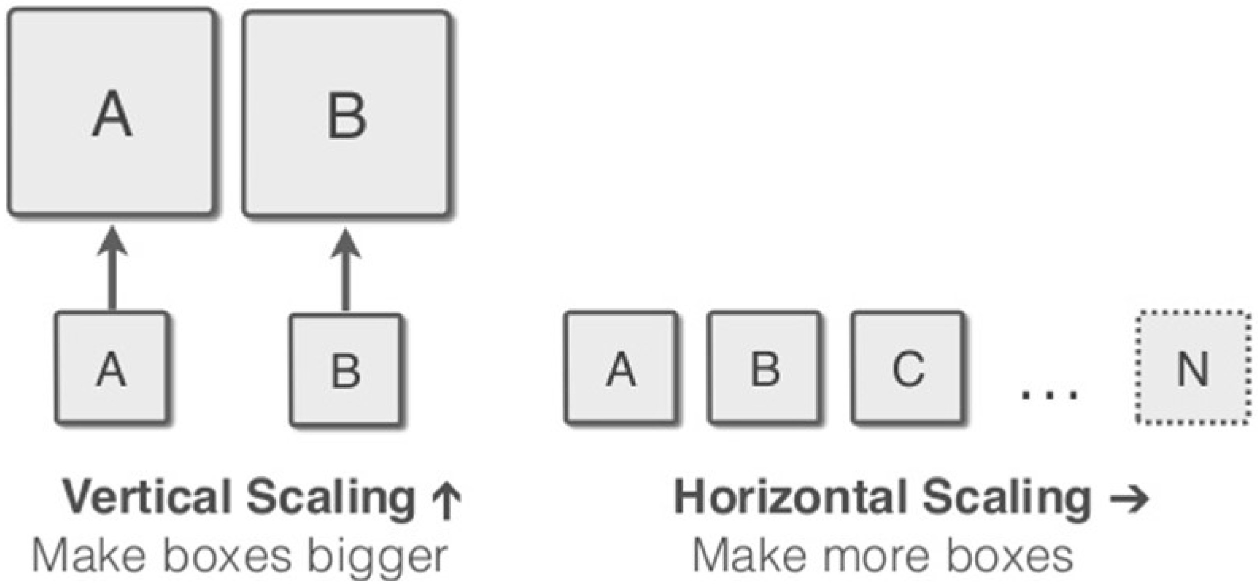
W. Gropp, E. Lusk, and R. Thakur, Using MPI-2: Advanced Features of the Message Passing Interface, MIT Press, ISBN 0-262-57132-3, 1999.

Scale Out vs Scale Up

Scale Out vs Scale Up



Scale Out vs Scale Up



Vertical Scaling	Horizontal Scaling
Higher Capital Investment	On Demand Investment
Utilization concerns	Utilization can be optimized
Relatively Quicker and works with the current design	Relatively more time consuming and needs redesigning
Limiting Scale	Internet Scale

Parallel Systems Architects Wanted

Parallel Systems Architects Wanted

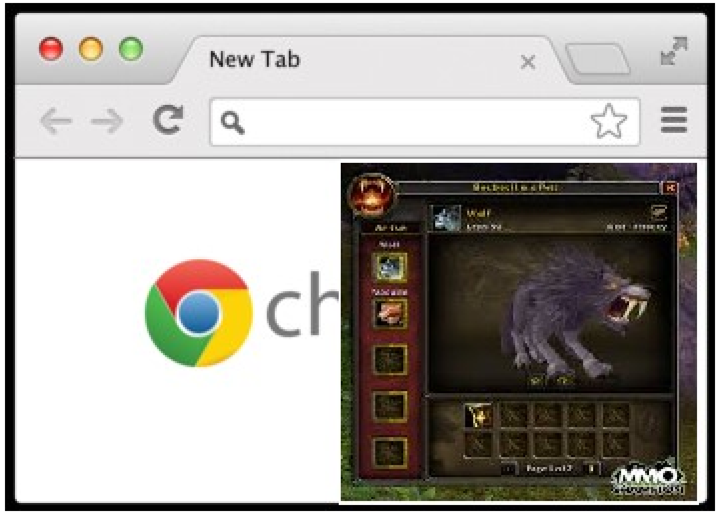
Hot Startup Idea:

www.purchase-a-pooch.biz

Parallel Systems Architects Wanted

Parallel Systems Architects Wanted

1. User Browses Potential Pets



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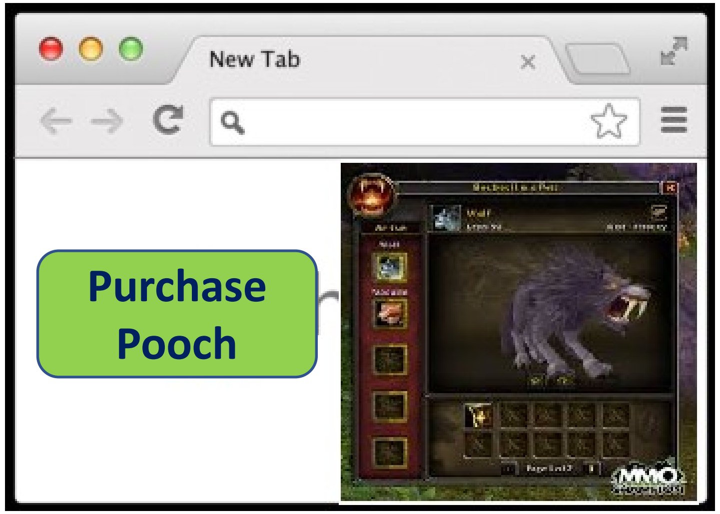

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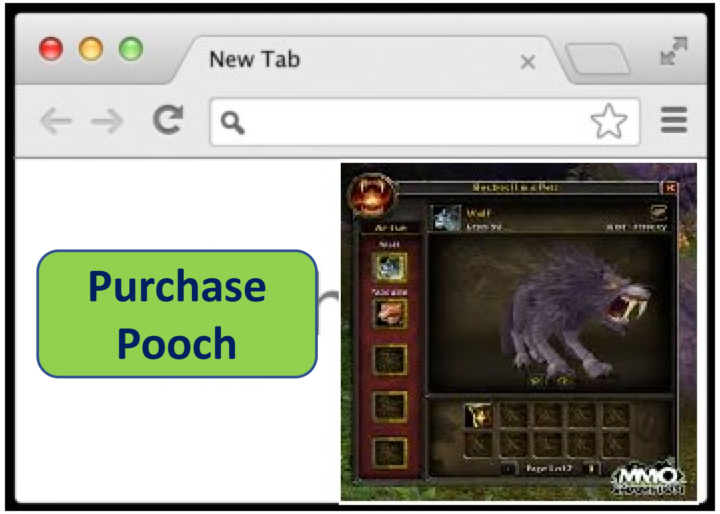

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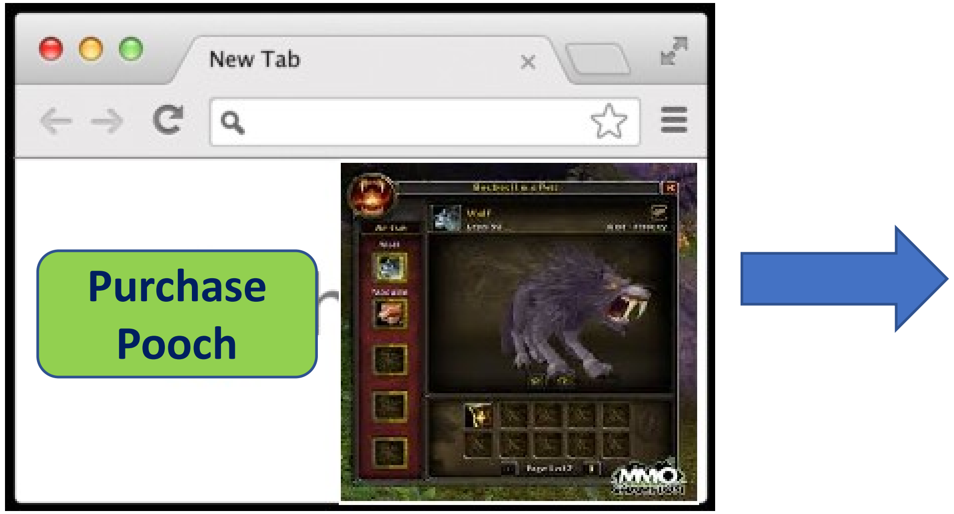
4. Pooch delivered (not shown)



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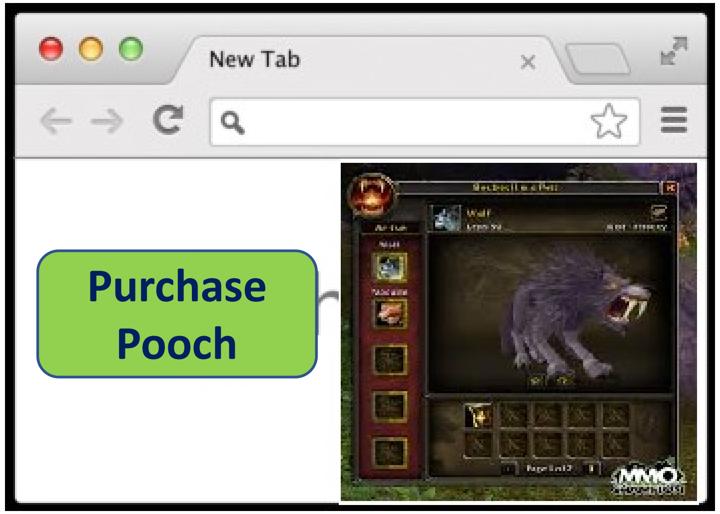
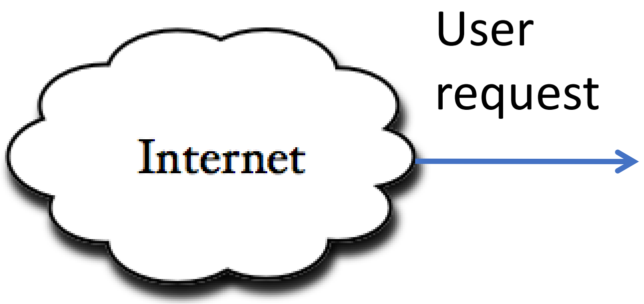
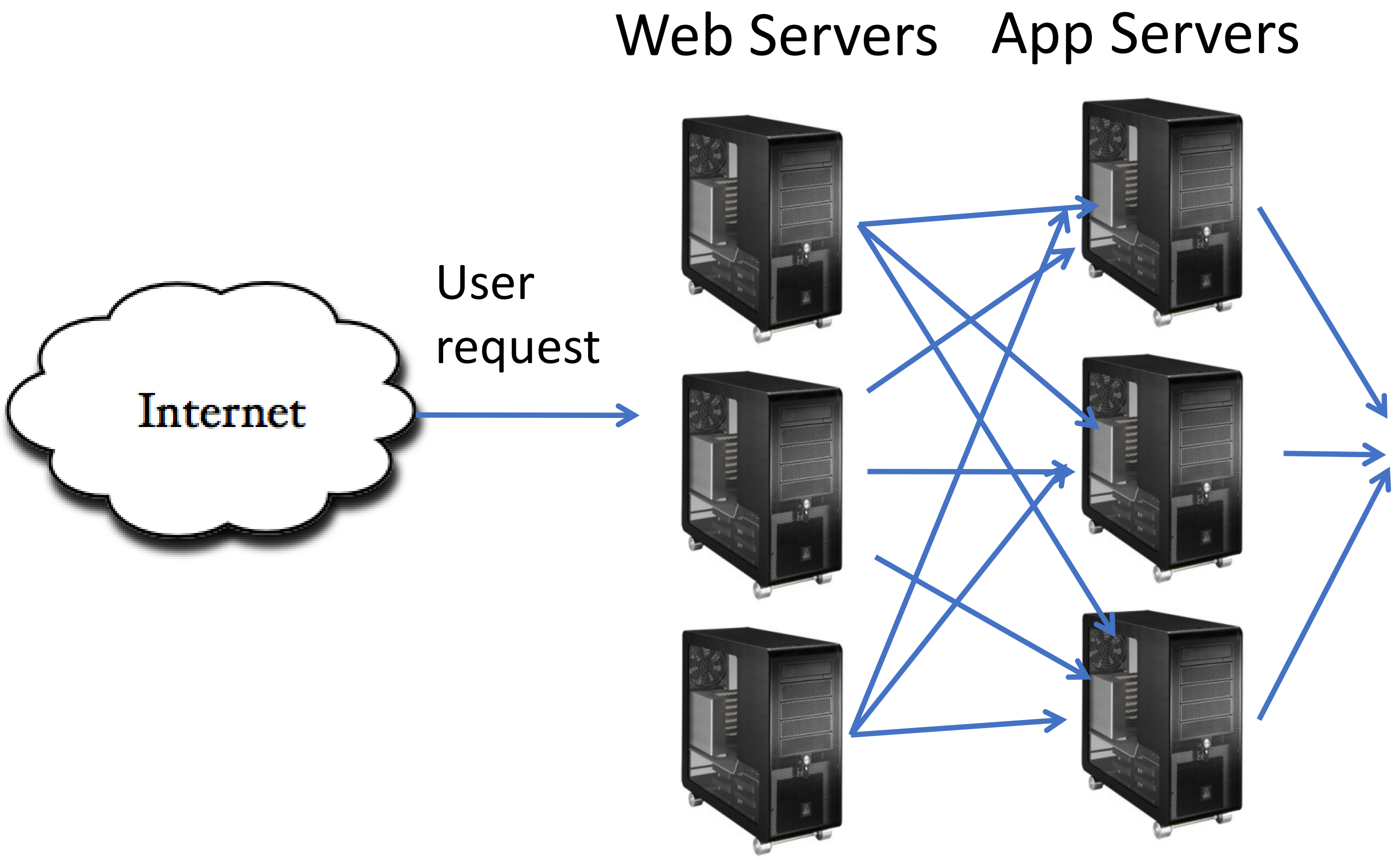


How to handle lots and lots of dogs?

3 Tier architecture

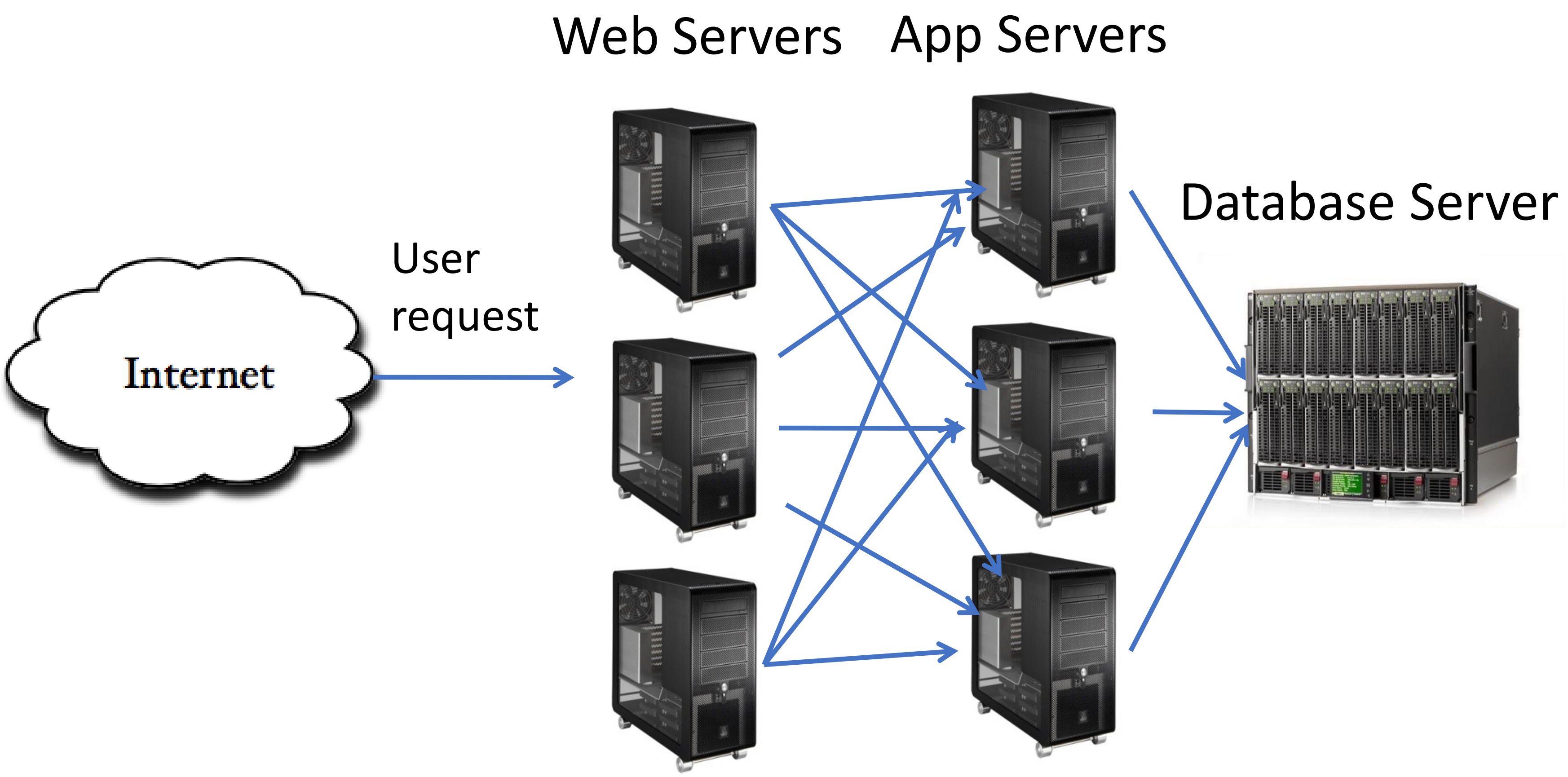


3 Tier architecture



Web Servers (Presentation Tier) and App servers (Business Tier) scale *horizontally*

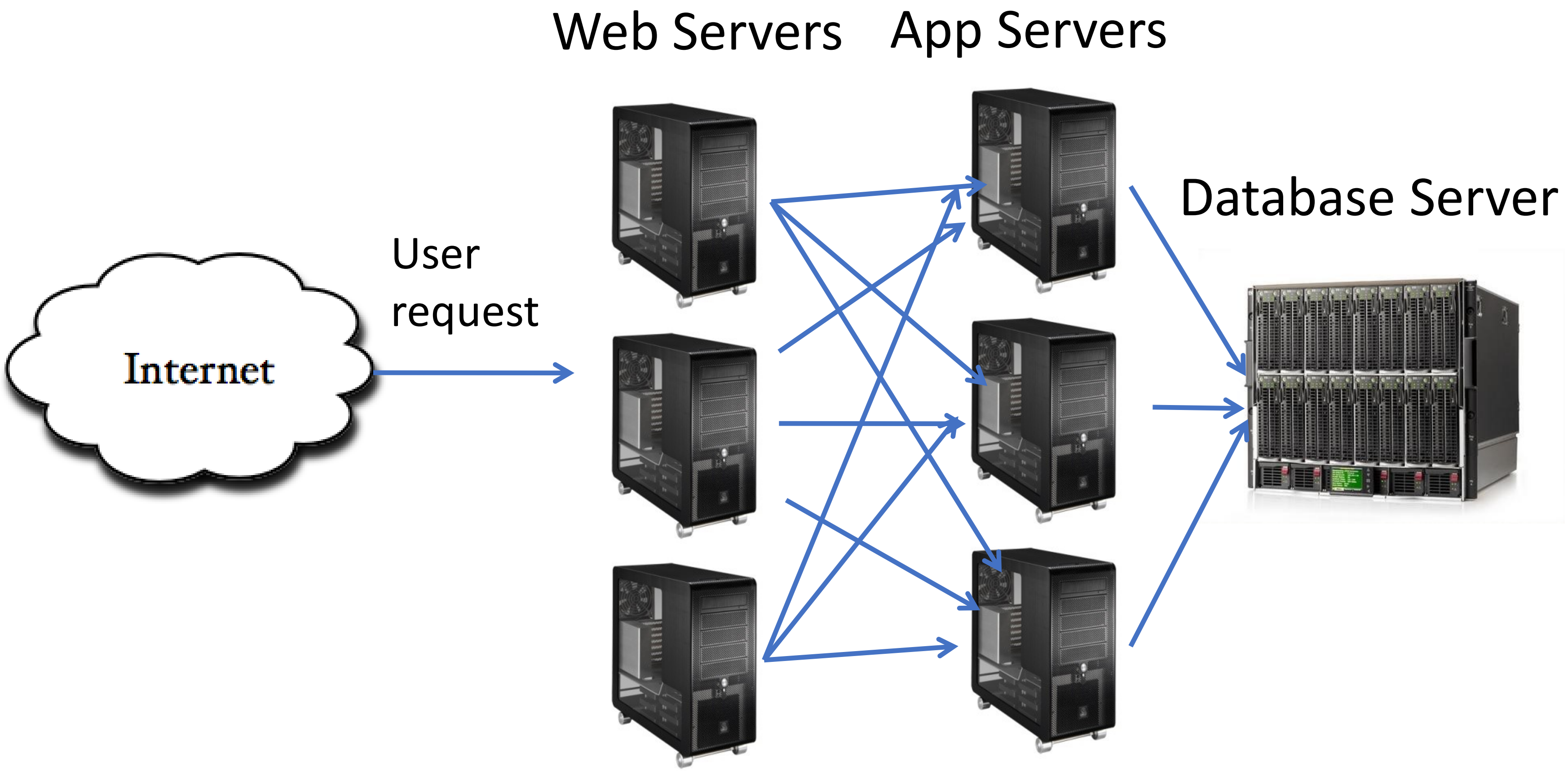
3 Tier architecture



Web Servers (Presentation Tier) and App servers (Business Tier) scale *horizontally*
Database Server → scales *vertically*

Horizontal Scale → "Shared Nothing"

3 Tier architecture



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Why is this a good arrangement?

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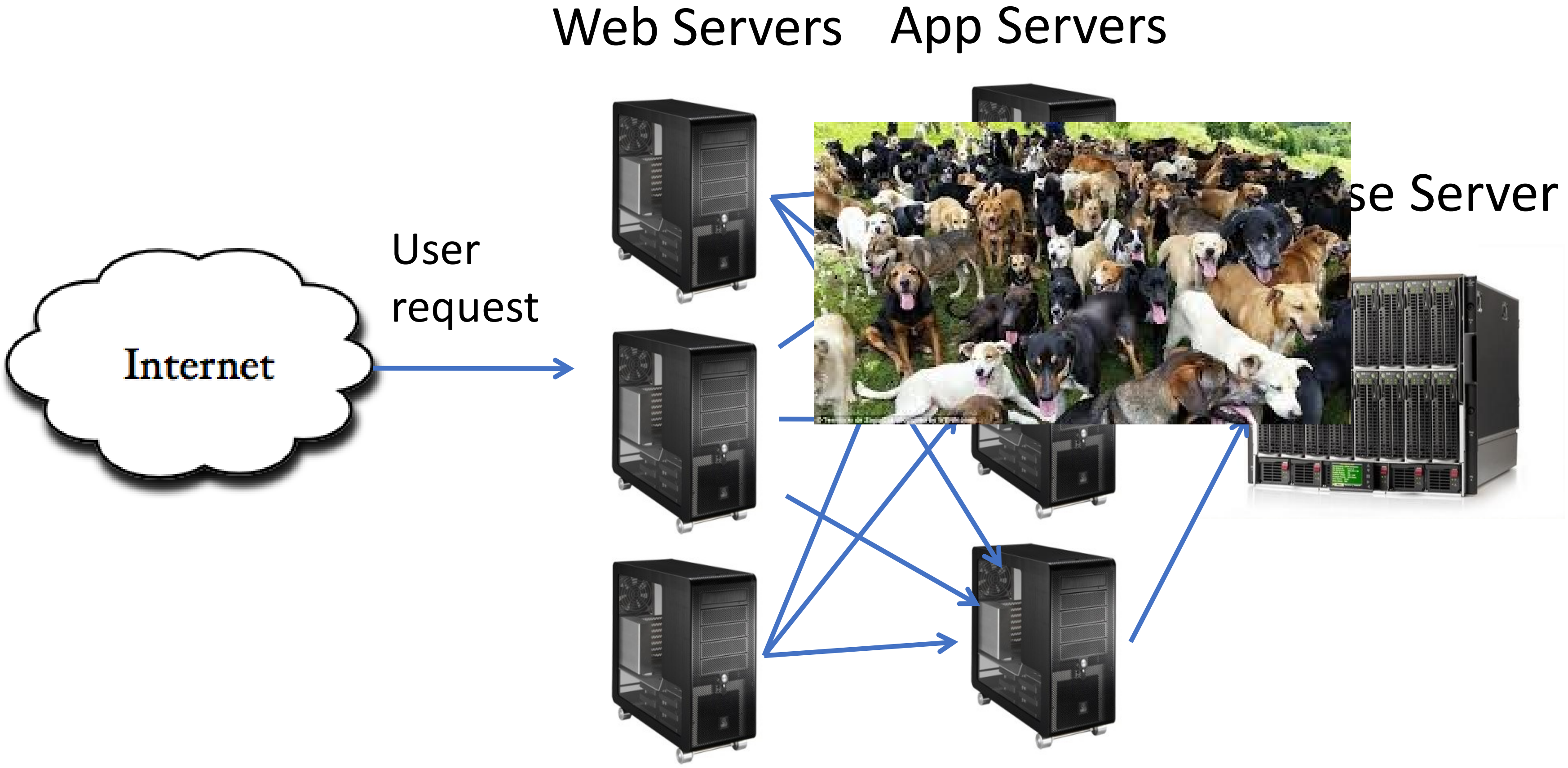

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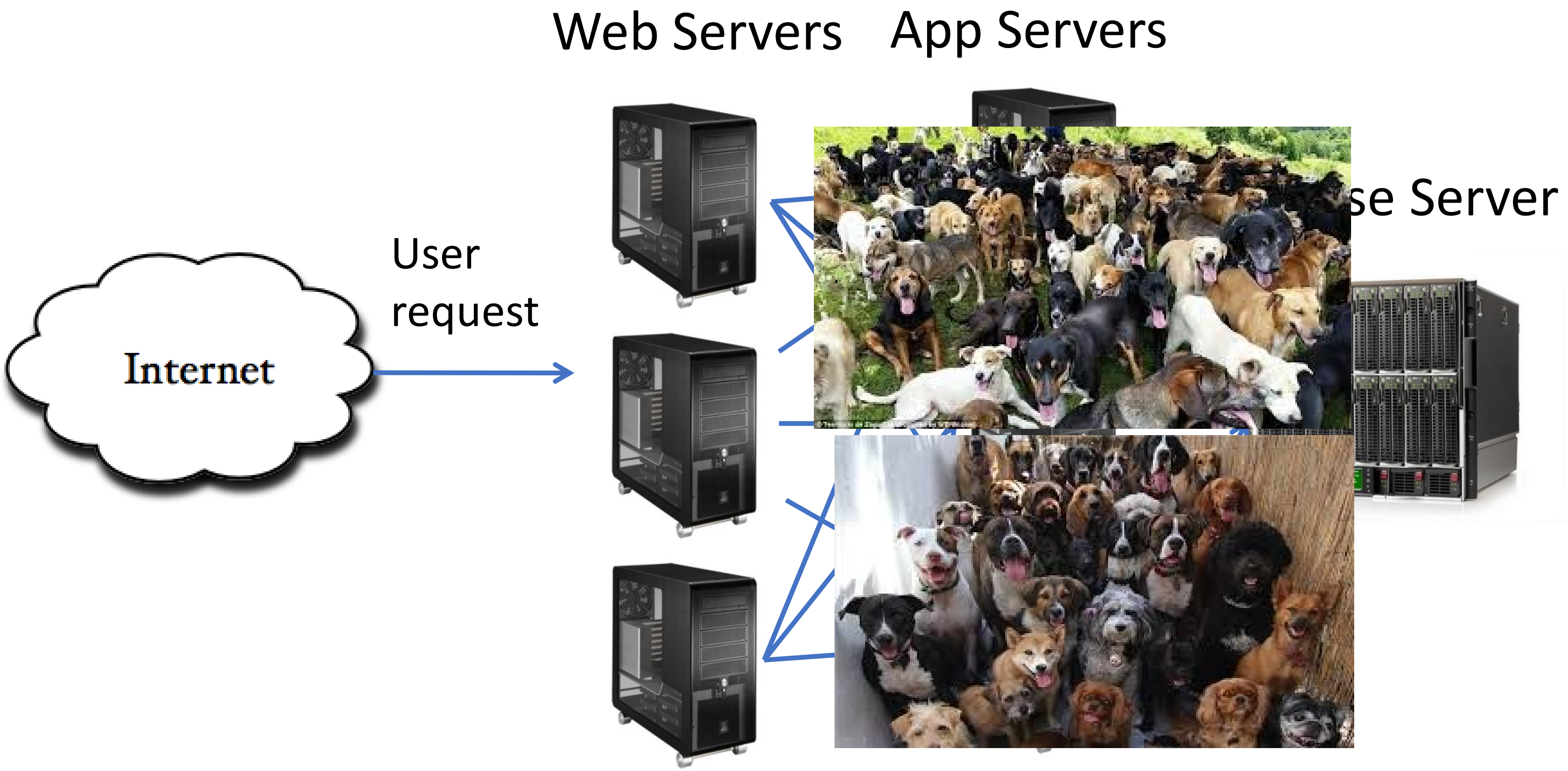

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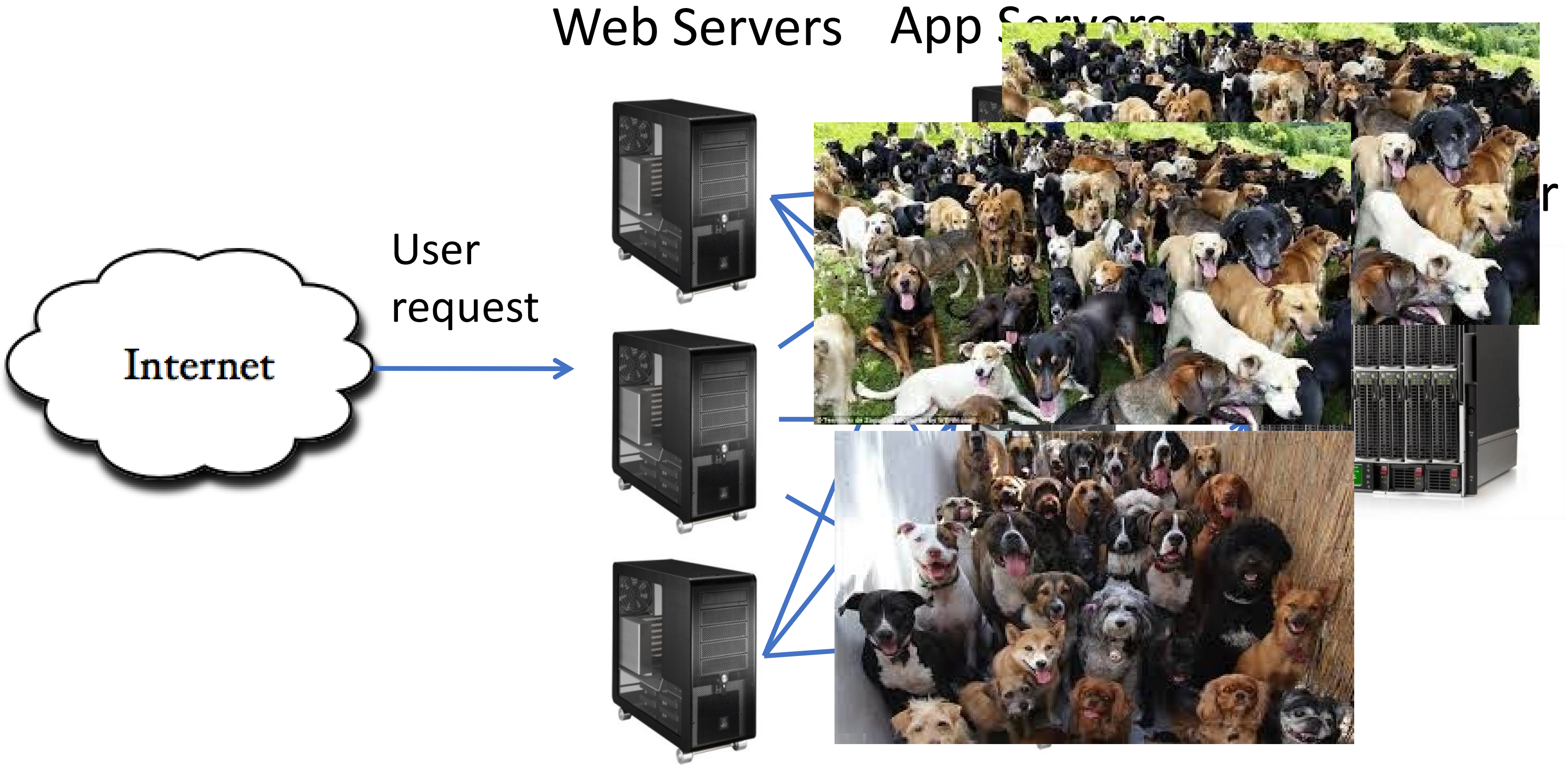

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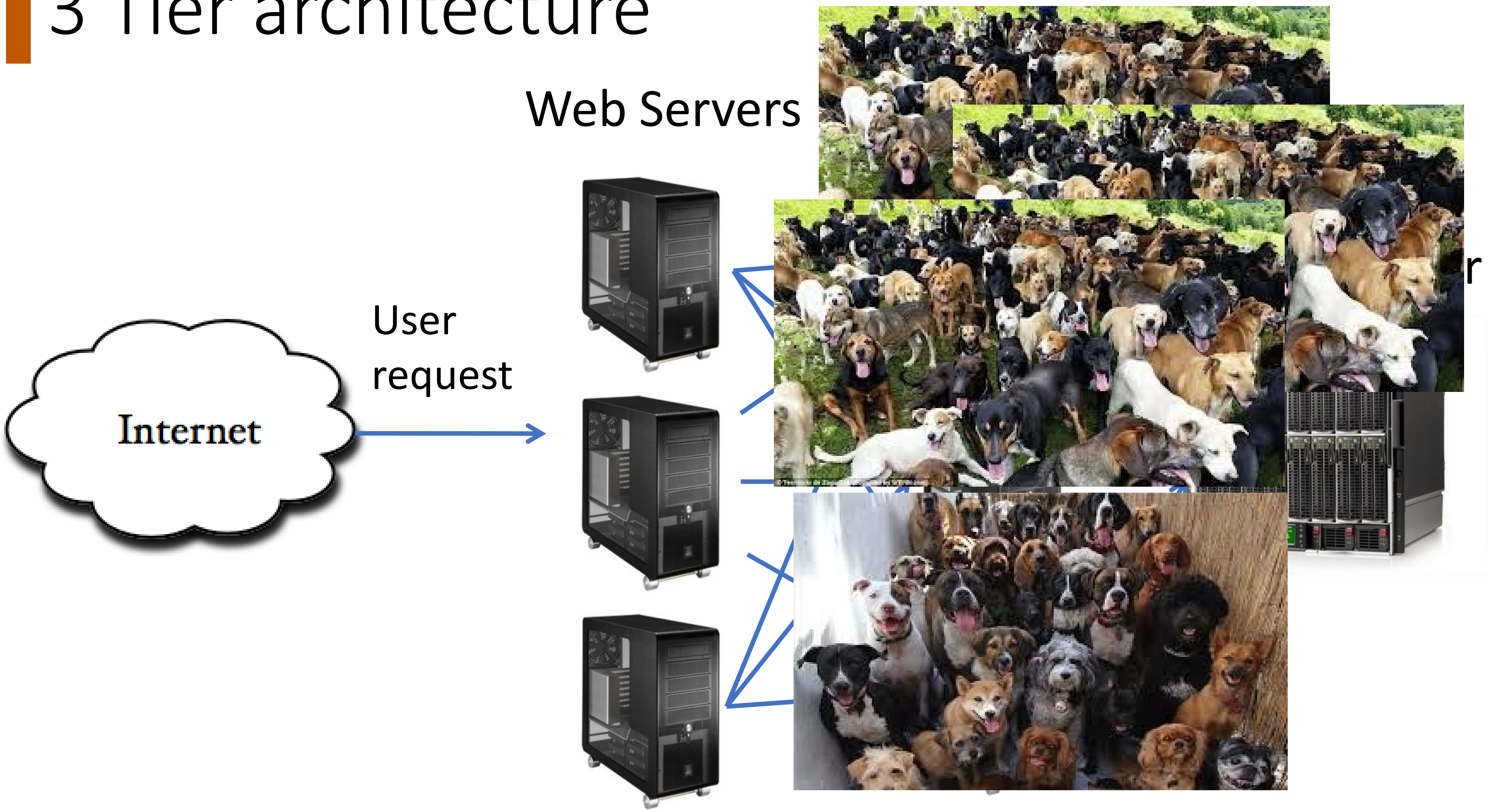

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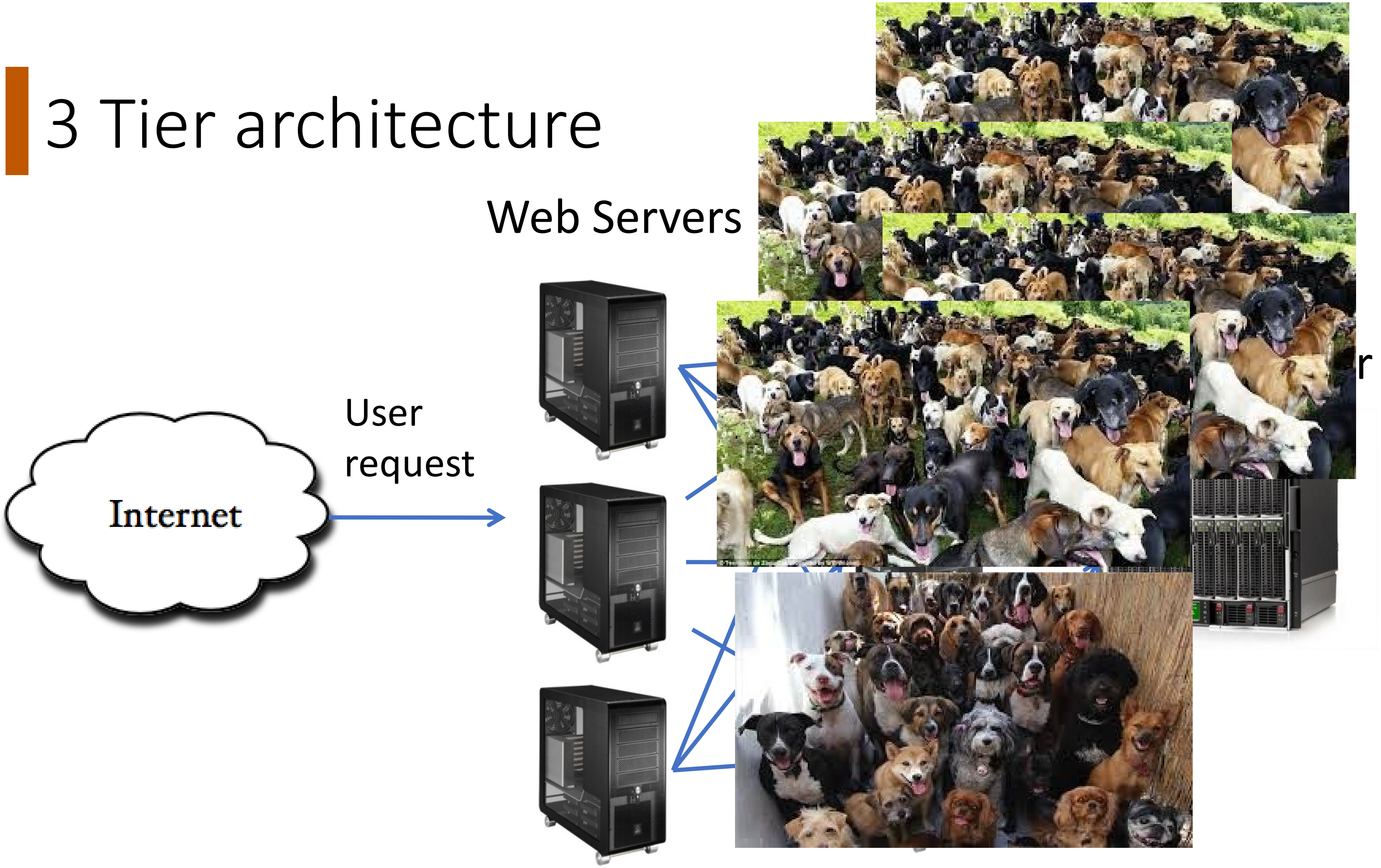

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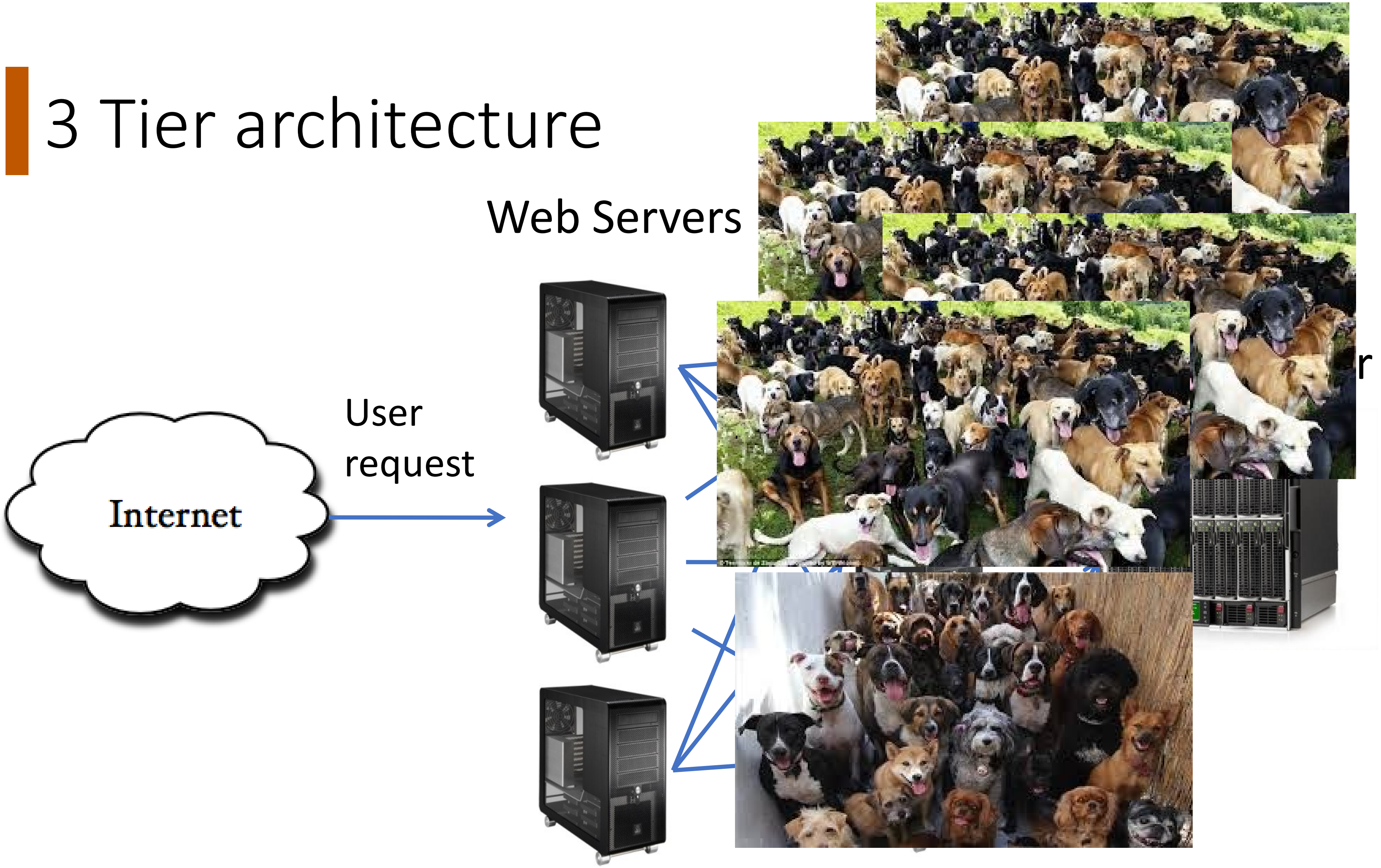


Web Servers (Presentation Tier) and Ap… …izontally

Database Server → scales *vertically*

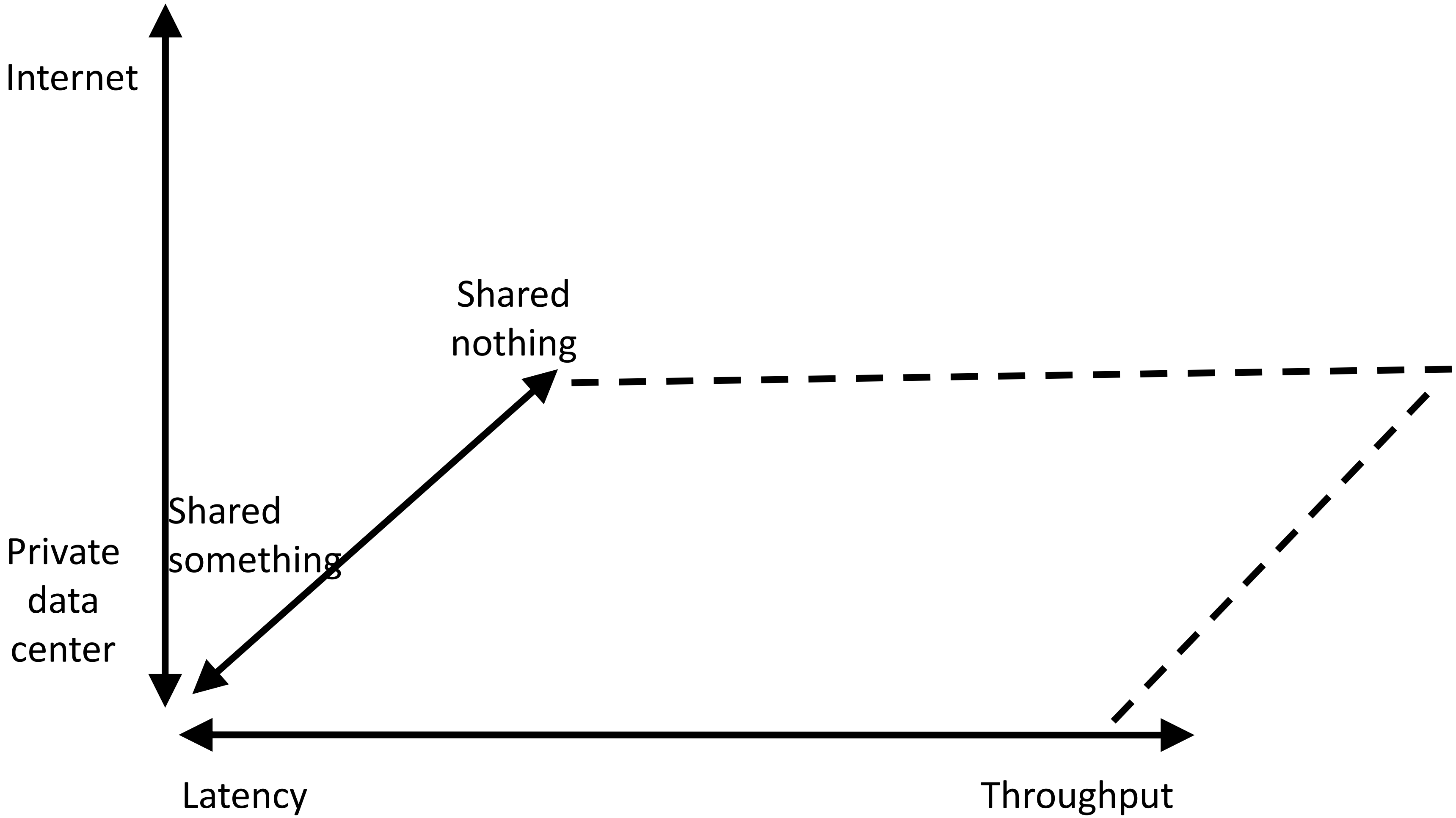
Horizontal Scale → "Shared Nothing"

Why is this a good arrangement?

Vertical scale gets you a long way, but there is always a bigger problem size

Horizontal Scale: Goal

Design Space



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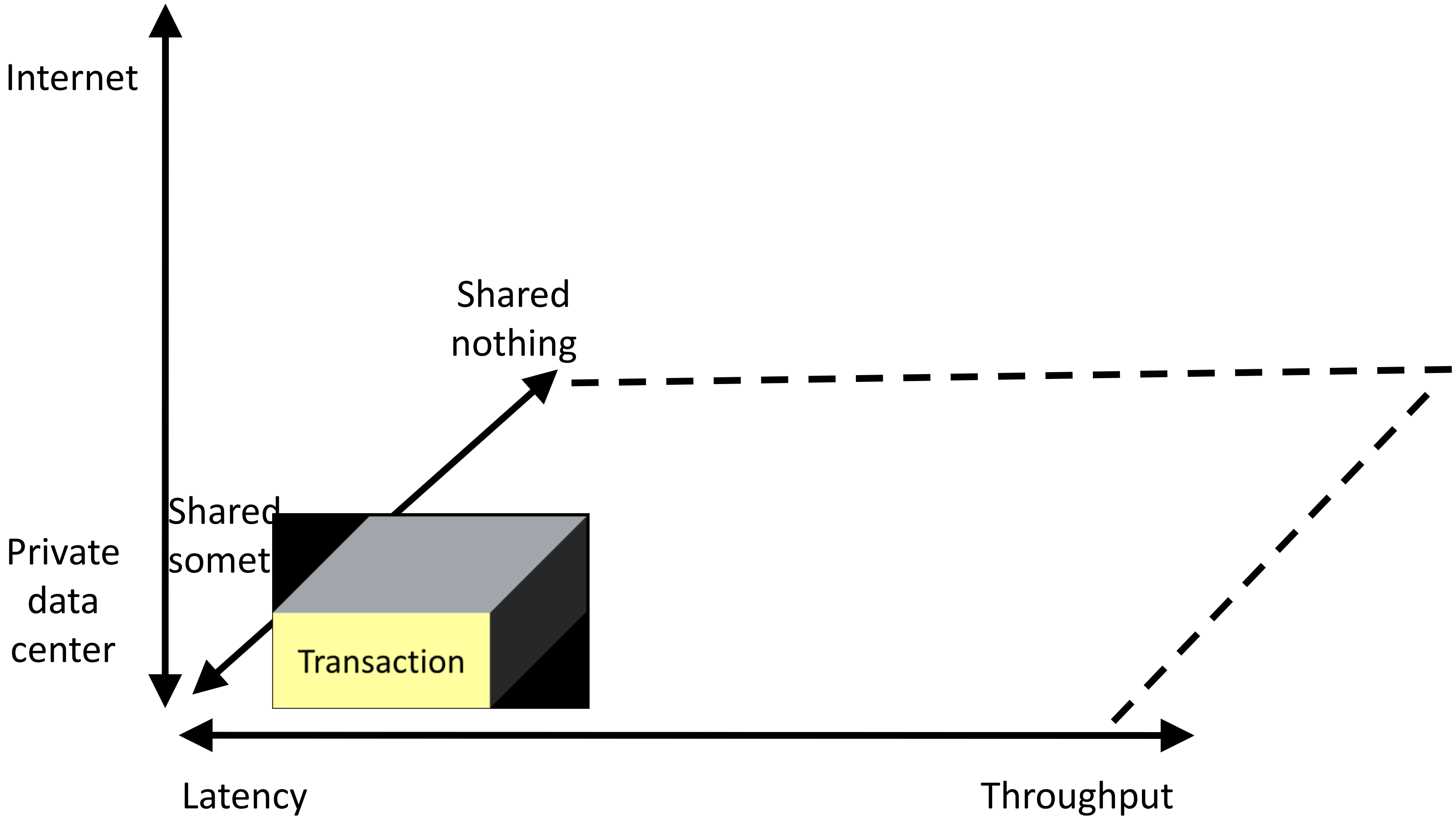
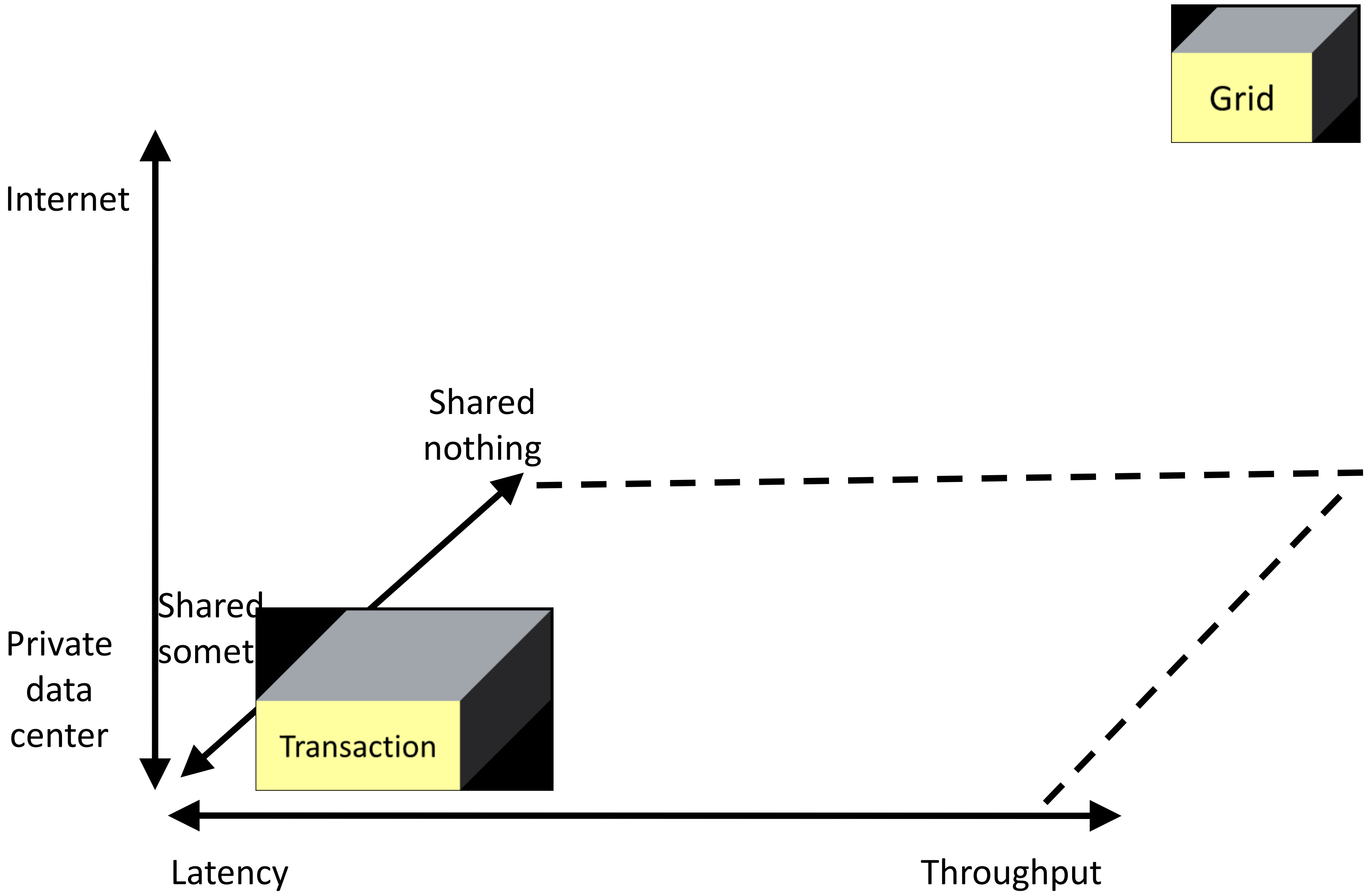


Design Space



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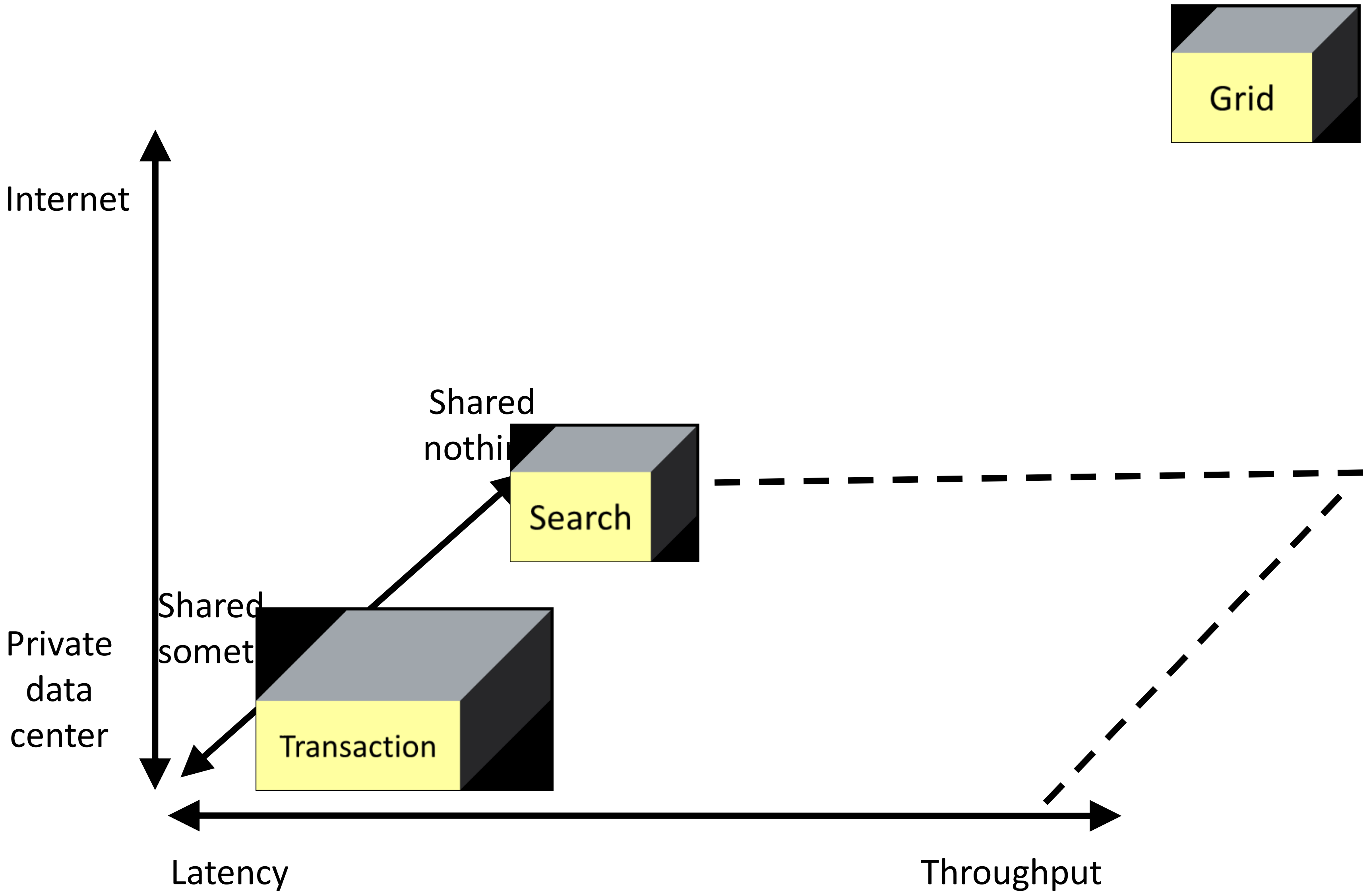

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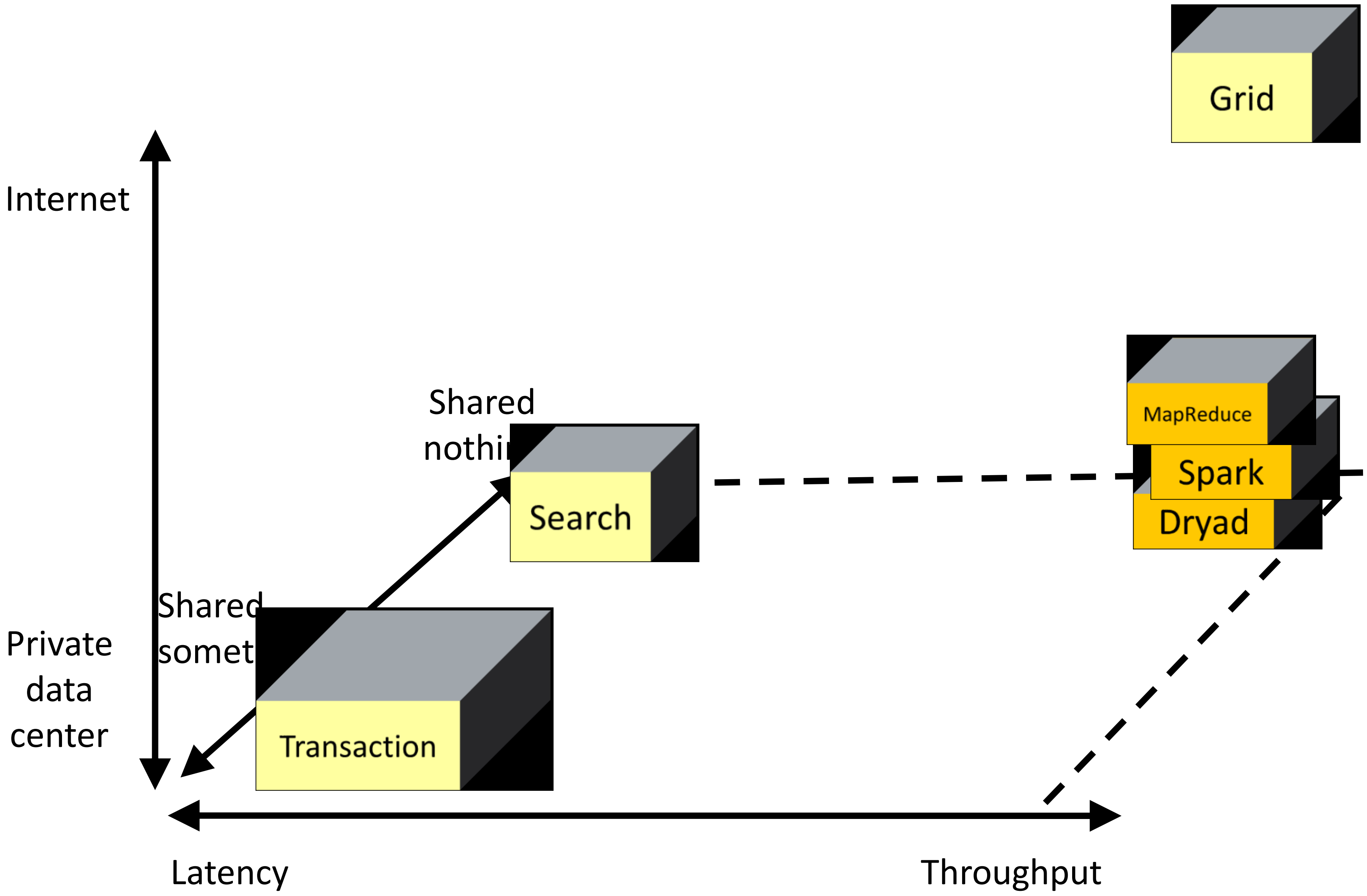

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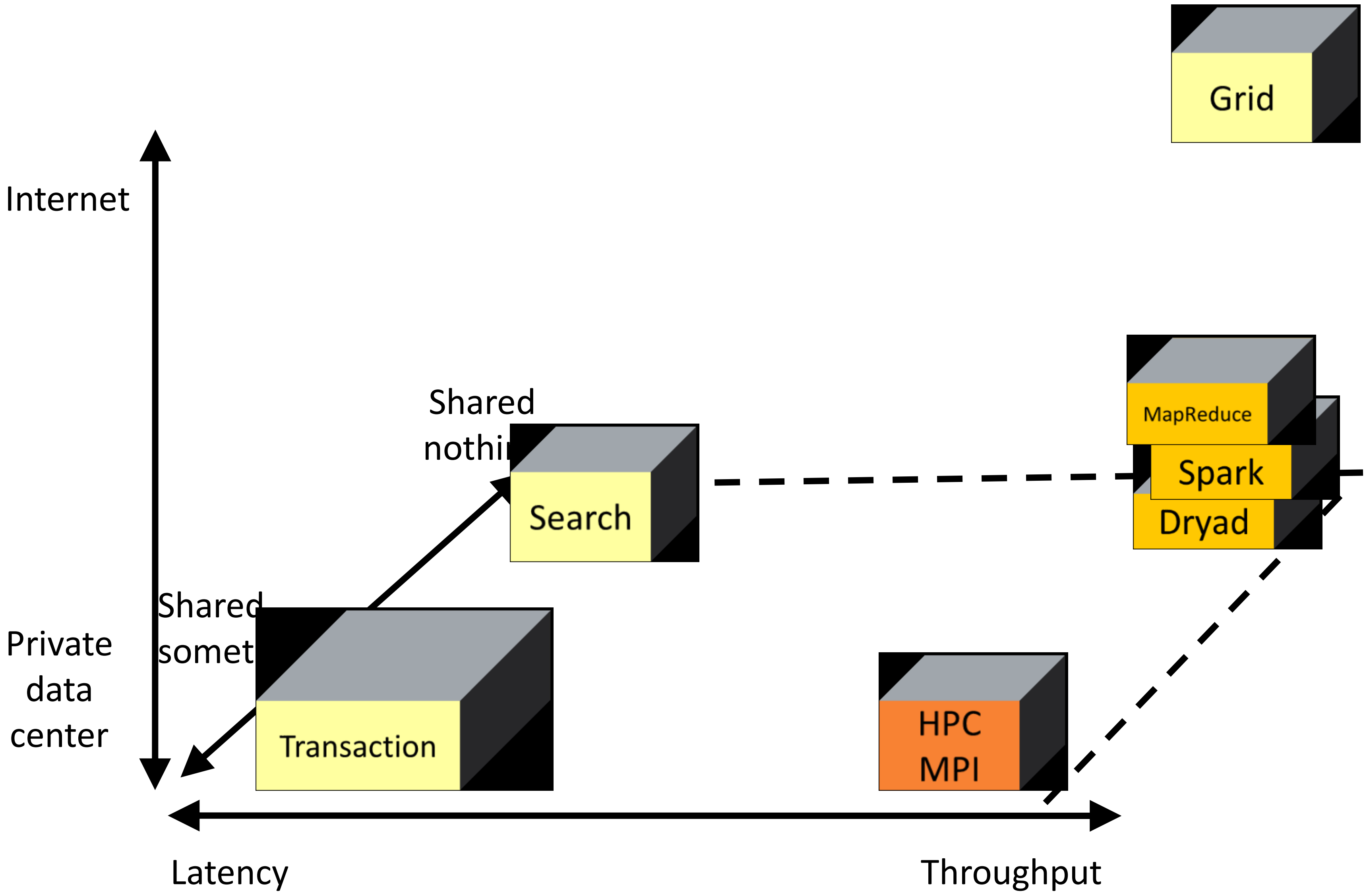

Parallel Architectures and MPI

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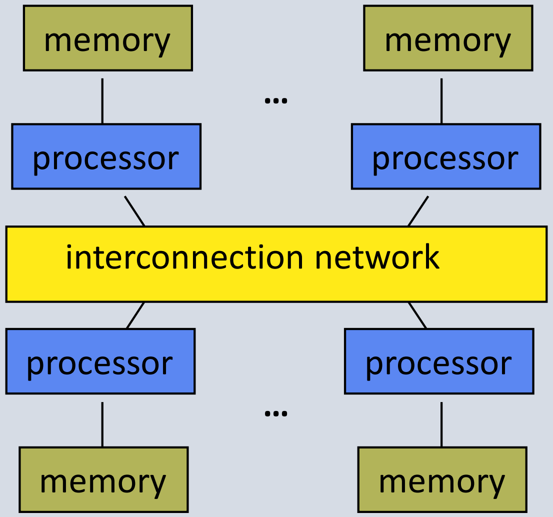
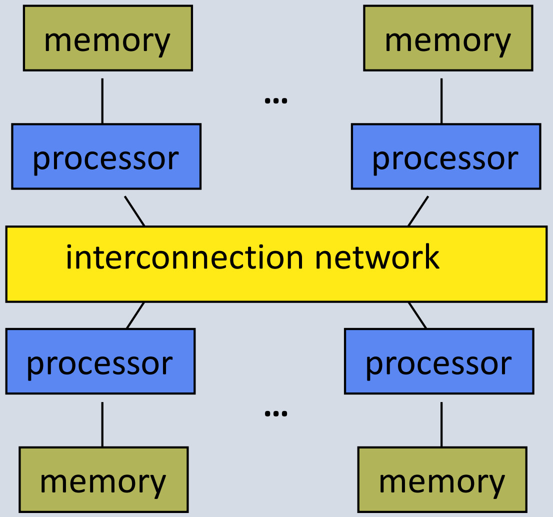


Parallel Architectures and MPI

Distributed Memory Multiprocessor

Messaging between nodes



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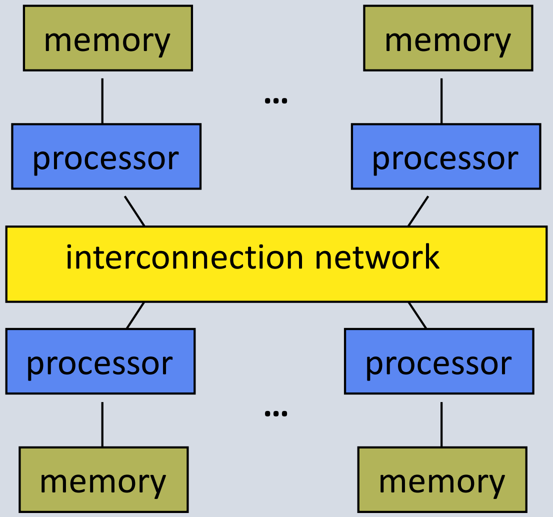

Massively Parallel Processor (MPP)

Many, many processors

Parallel Architectures and MPI

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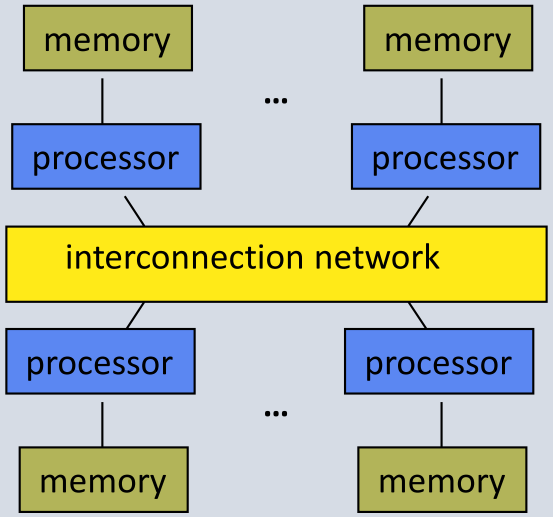

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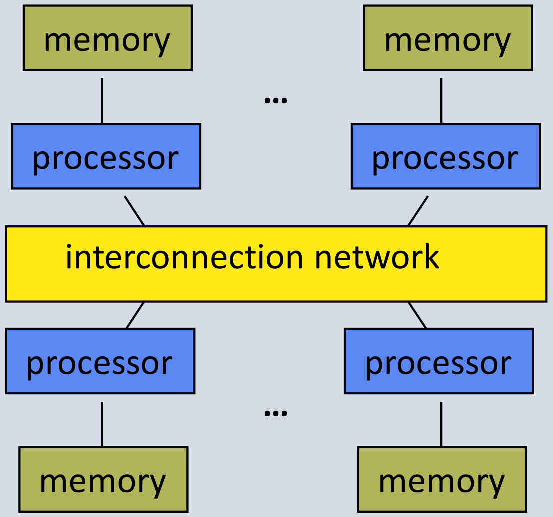

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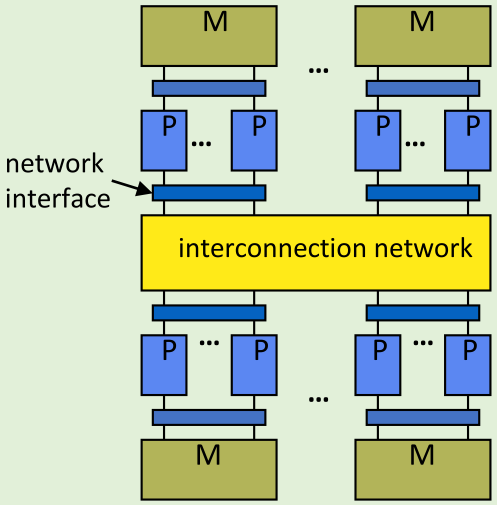
Cluster of SMPs

- Shared memory in SMP node
- Messaging ←→ SMP nodes

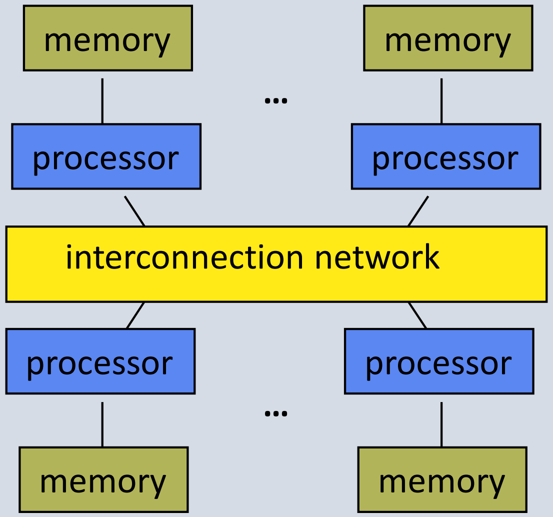


- also regarded as MPP if processor # is large

Parallel Architectures and MPI

Distributed Memory Multiprocessor

Messaging between nodes



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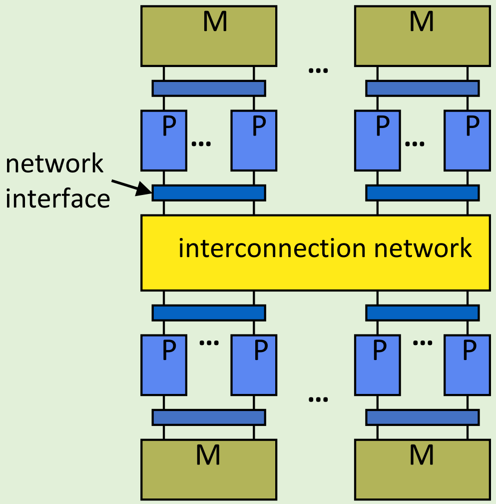
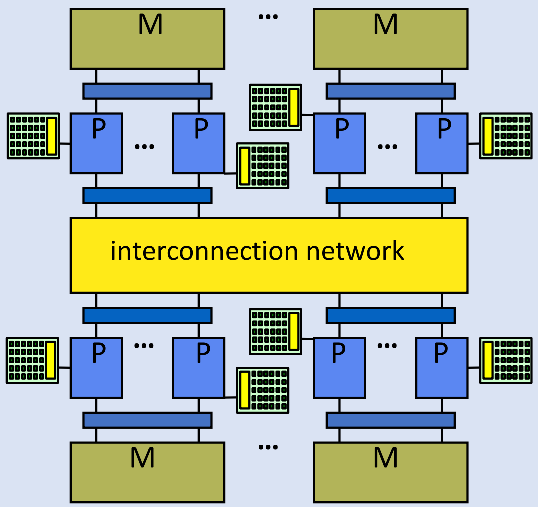


- also regarded as MPP if processor # is large

Multicore SMP+GPU Cluster

- Shared mem in SMP node
- Messaging between nodes

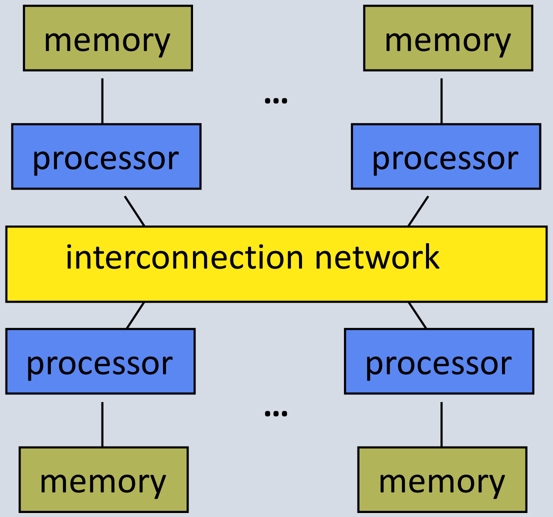


- GPU accelerators attached

Parallel Architectures and MPI

Distributed Memory Multiprocessor

Messaging between nodes



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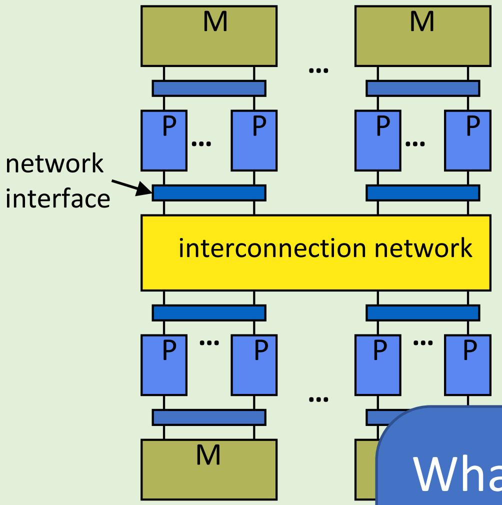

- also regarded
  processor # is

Multicore SMP+GPU Cluster

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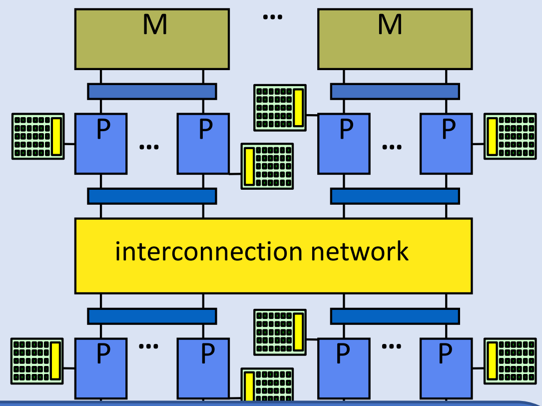
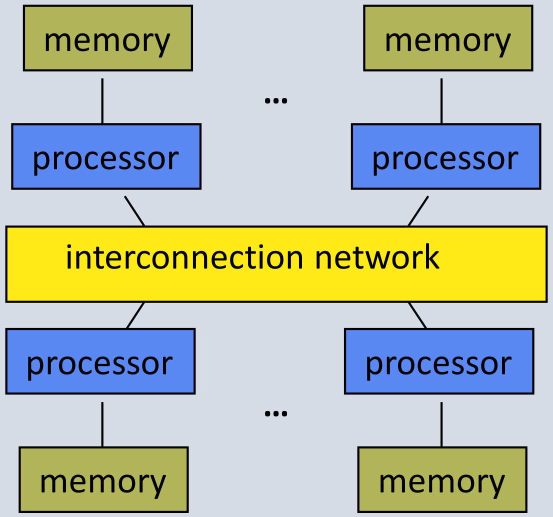


What have we left out?

Parallel Architectures and MPI

Distributed Memory Multiprocessor

Messaging between nodes



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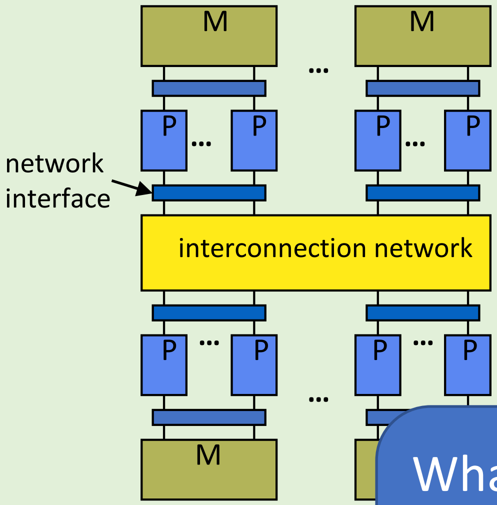

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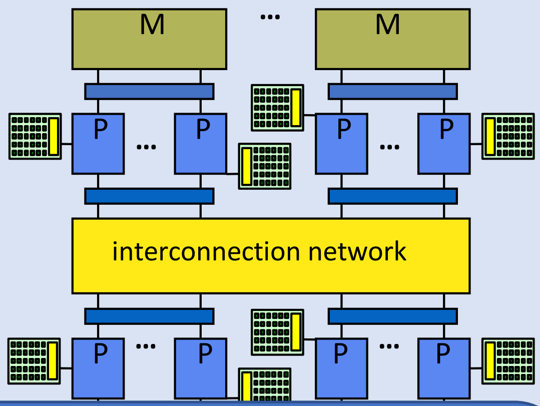

What have we left out?

- DSMs
- CMPs
- Non-GPU Accelerators

What requires extreme scale?

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Simulations—why?

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Simulations—why?

Simulations are sometimes more cost effective than experiments

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Why extreme scale?

More compute cycles, more memory, etc, lead for faster and/or more accurate simulations

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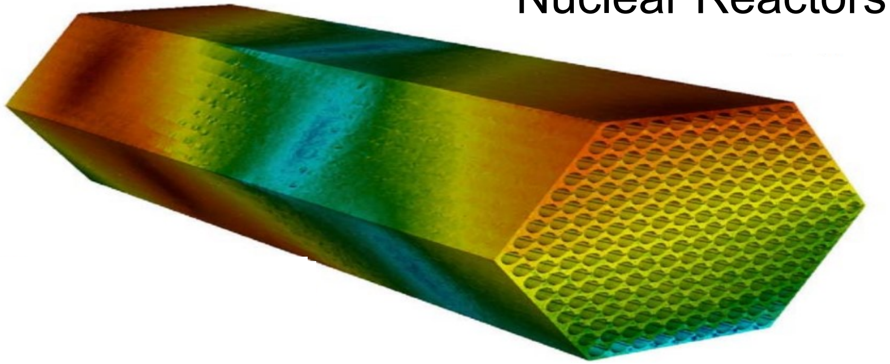
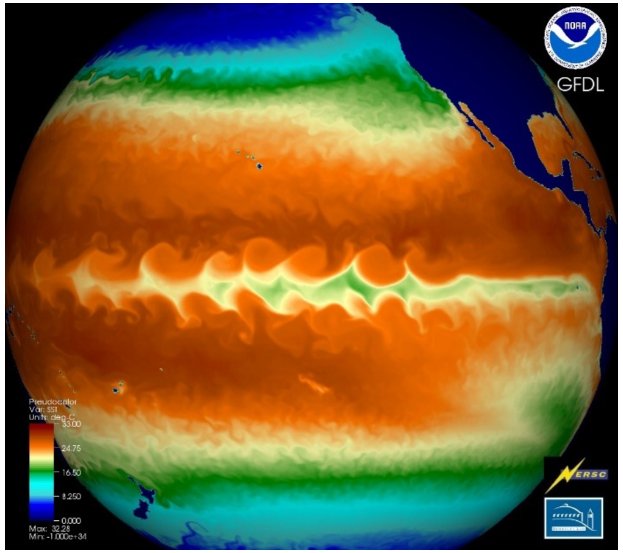
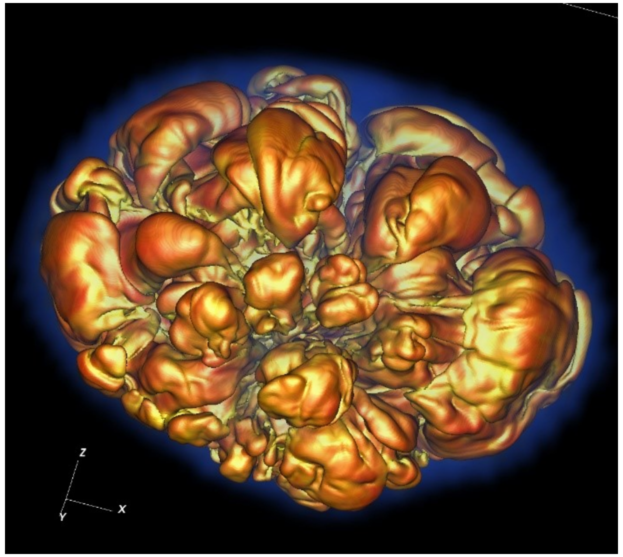
More compute cycles, more memory, etc, lead for faster and/or more accurate simulations

Nuclear Reactors





Climate Change



Astrophysics

Image credit: Prabhat, LBNL

How big is “extreme” scale?

Measured in FLOPs

FLoating point **O**perations **P**er **s**econd

- 1 GigaFLOP = 1 billion FLOPs
- 1 TeraFLOP = 1000 GigaFLOPs
- 1 PetaFLOP = 1000 TeraFLOPs
  - Most current super computers
- 1 ExaFLOP = 1000 PetaFLOPs
  - Arriving in 2018 (supposedly)

How big is "extreme" scale?

Measured in FLOPs

FLoating point **O**perations **P**er **s**econd

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
2	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P , NUDT National Super Computer Center in Guangzhou China	3,120,000	33,862.7	54,902.4	17,808
3	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland	361,760	19,590.0	25,326.3	2,272
4	**Gyoukou** - ZettaScaler-2.2 HPC system, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 700Mhz , ExaScaler Japan Agency for Marine-Earth Science and Technology Japan	19,860,000	19,135.8	28,192.0	1,350
5	**Titan** - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States	560,640	17,590.0	27,112.5	8,209
6	**Sequoia** - BlueGene/Q, Power BQC 16C 1.60 GHz, Custom , IBM DOE/NNSA/LLNL	1,572,864	17,173.2	20,132.7	7,890

How big is “extreme” scale?

Measured in FLOPs

FLoating point **O**perations **P**er second

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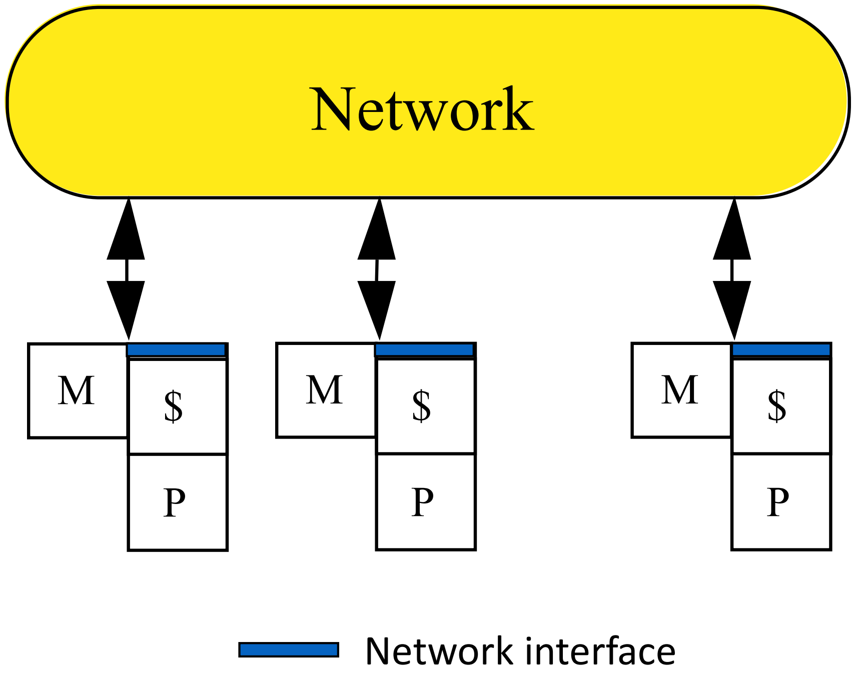
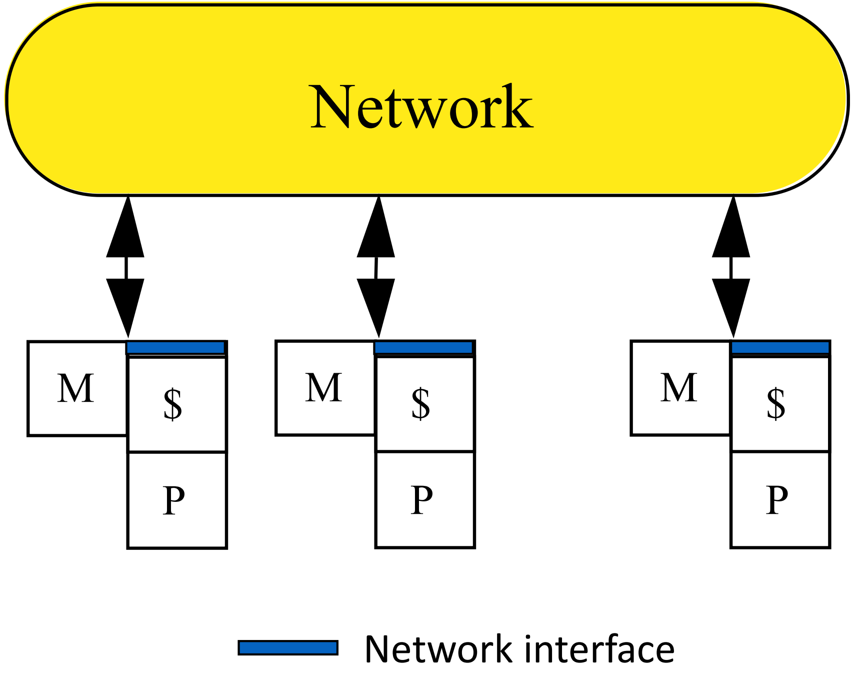


Distributed Memory Multiprocessors

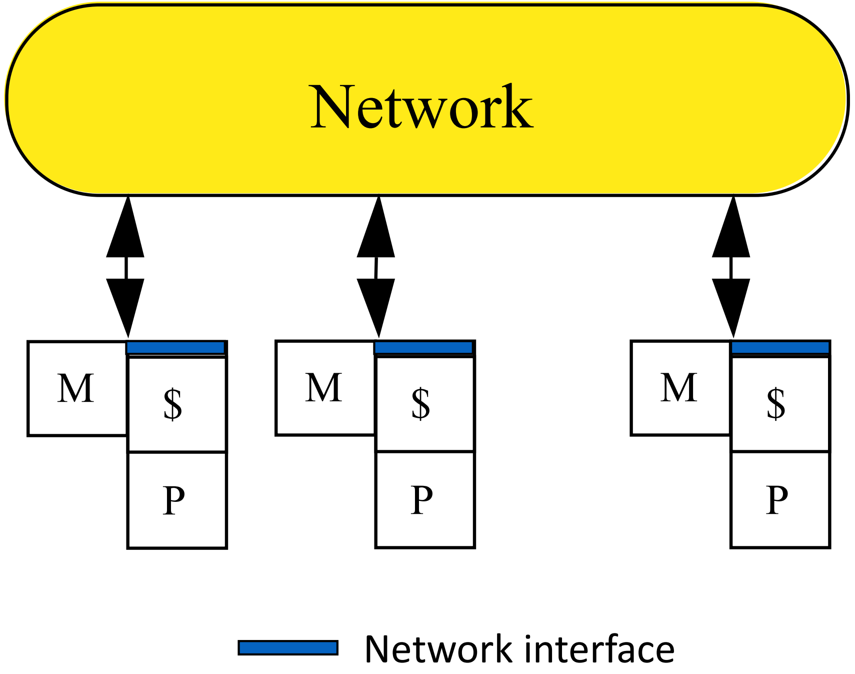


- Nodes: complete computer
  - Including I/O
- Nodes communicate via network
  - Standard networks (IP)
  - Specialized networks (RDMA, fiber)

Distributed Memory Multiprocessors

Each processor has a local memory

Physically separated address space



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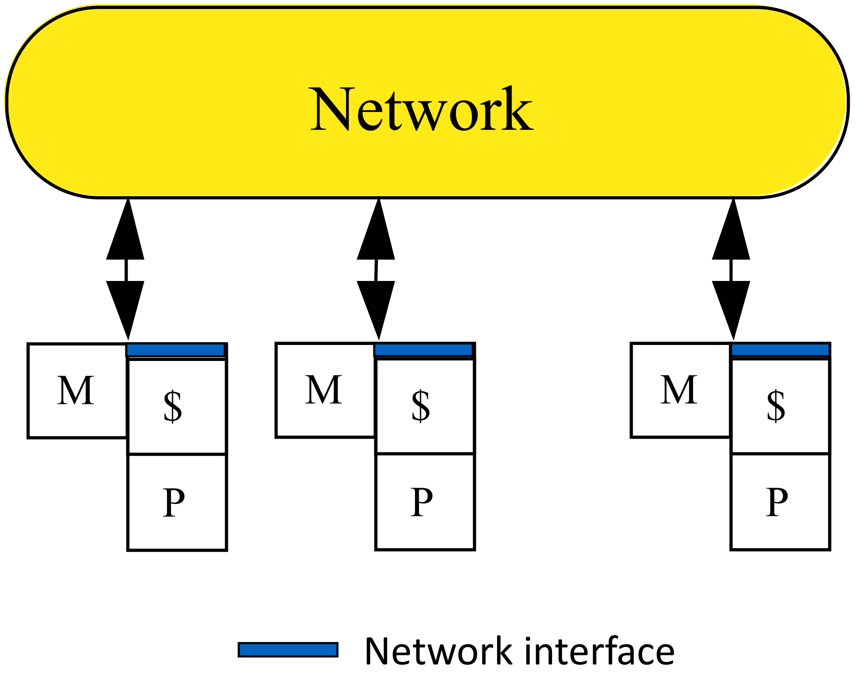
Distributed Memory Multiprocessors

Each processor has a local memory

- Physically separated address space

Processors communicate to access non-local data

- Message communication
  - *Message passing architecture*
- Processor interconnection network



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Distributed Memory Multiprocessors

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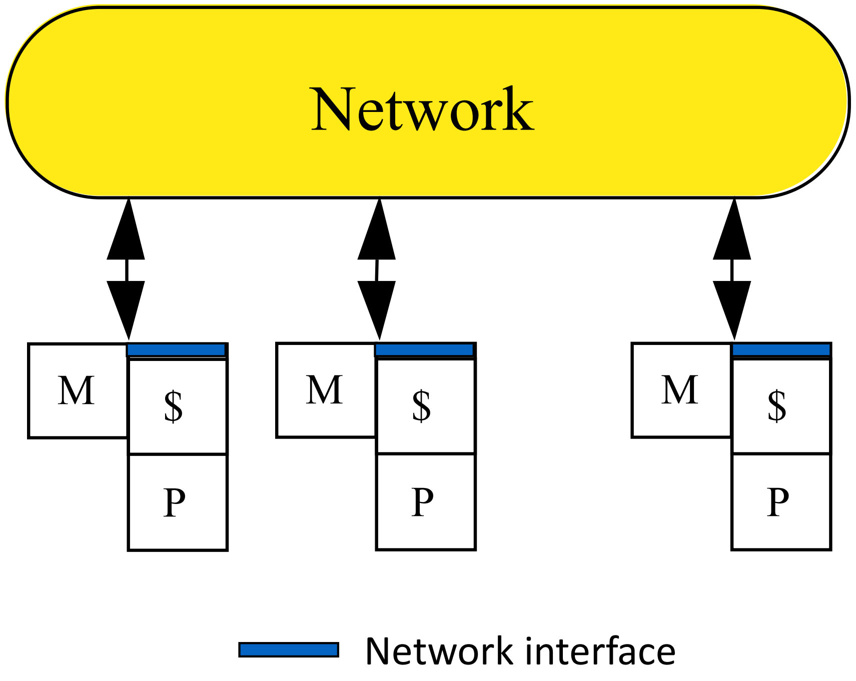

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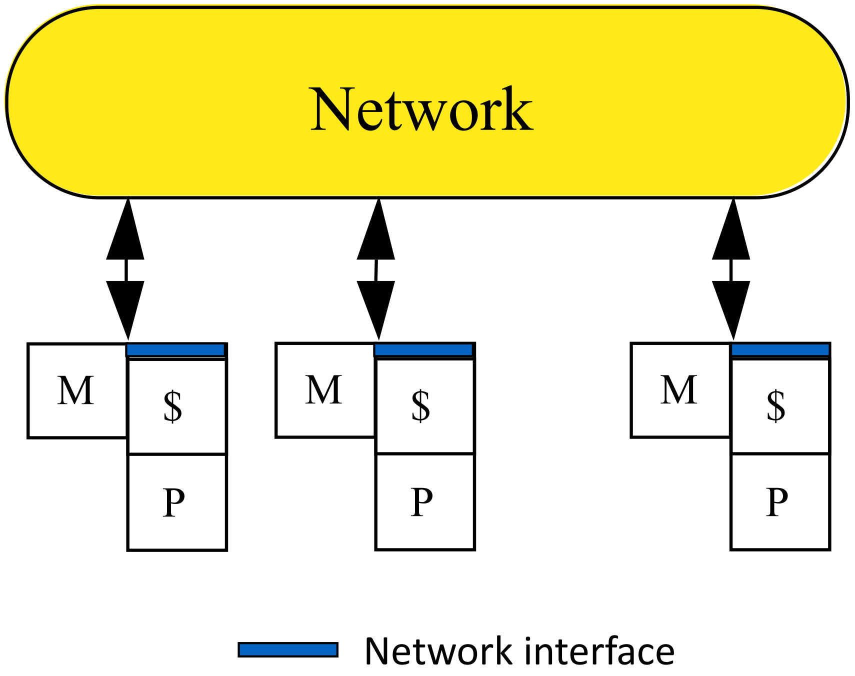
Scalable architecture
- Incremental cost to add hardware (cost of node)



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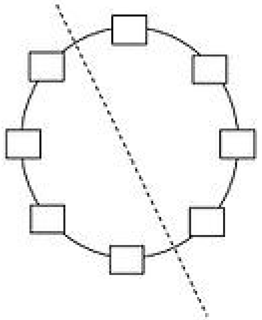

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Is this different from metrics we've cared about so far?

Ostensible Advantages of Distributed Memory Architectures

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Can you think of any *disadvantages*?

Running on Supercomputers

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- Programmer plans a ***job***; job ==
  - parallel binary program
  - “input deck” (specifies input data)
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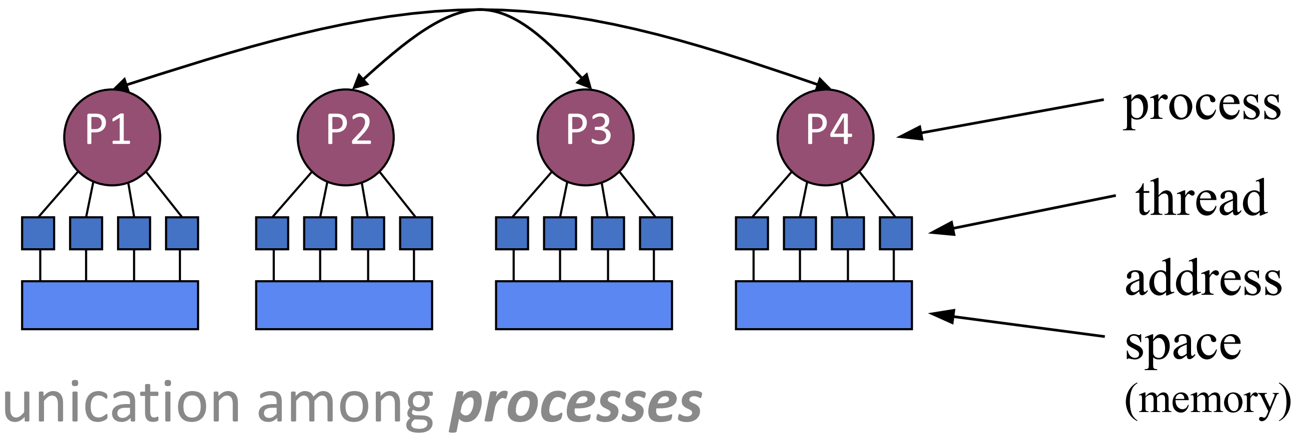
- MPI library interprets this information, hides the details

The Message-Passing Model

Process: a program counter and address space

Processes: multiple threads sharing a single address space



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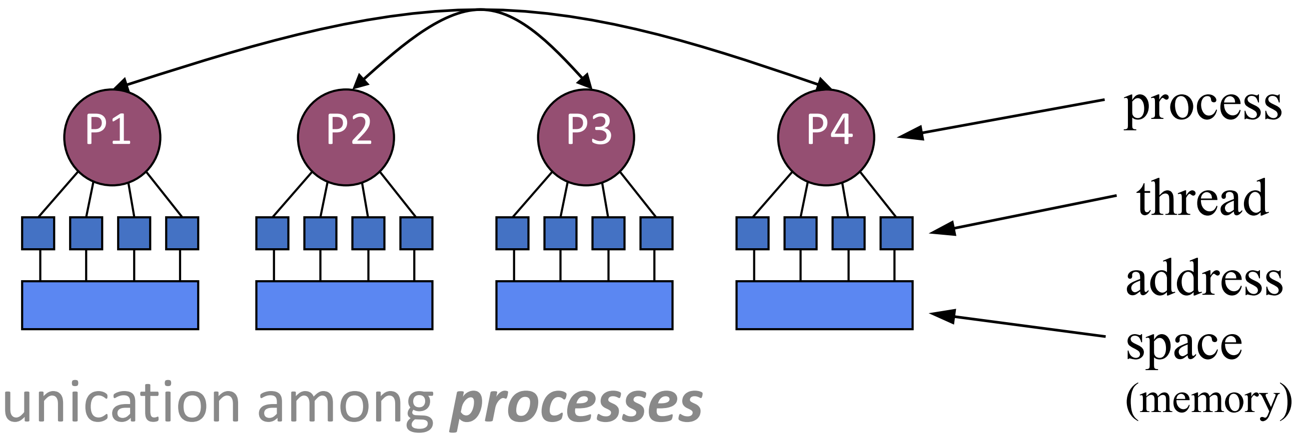

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How does this compare with CSP?

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Process: a program counter and address space

Proc

MPI

Inte

CSP?

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- Two flavors for communication
  - Cooperative operations
  - One-sided operations

Cooperative Operations

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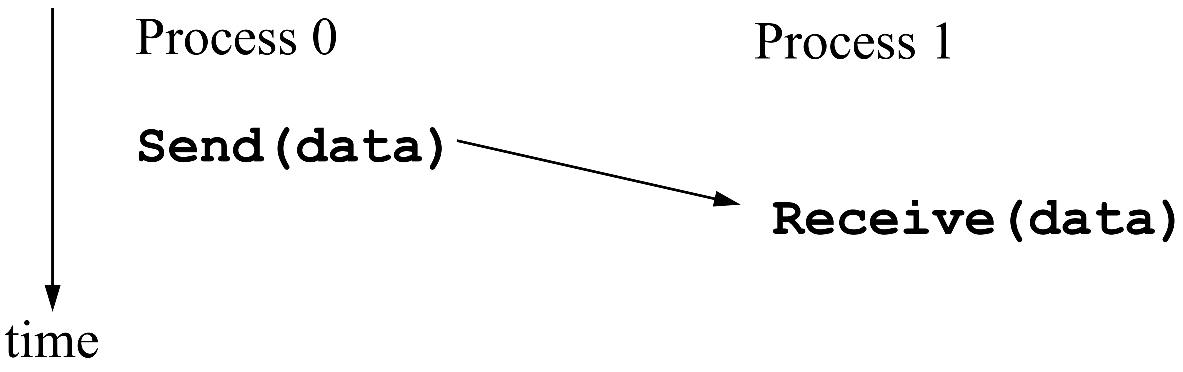

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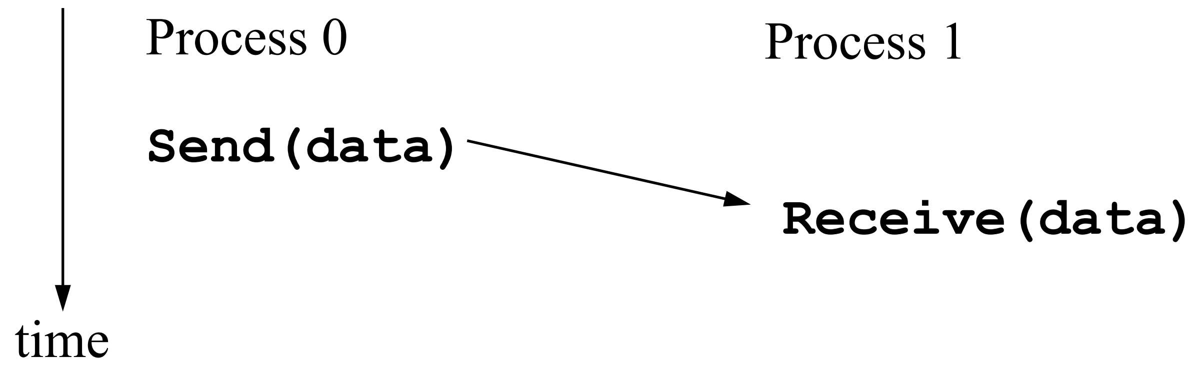

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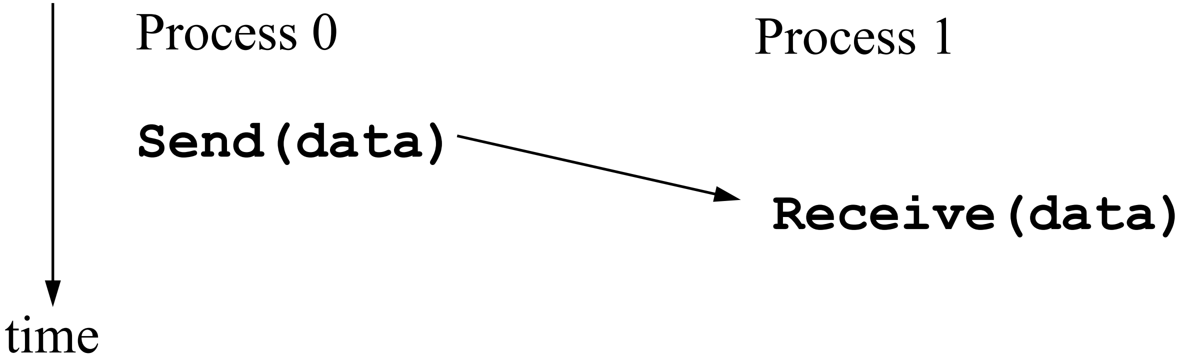

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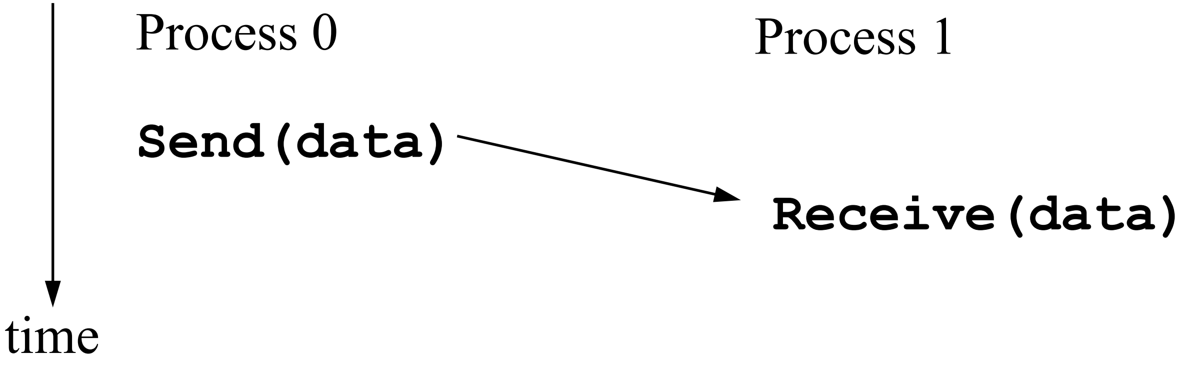

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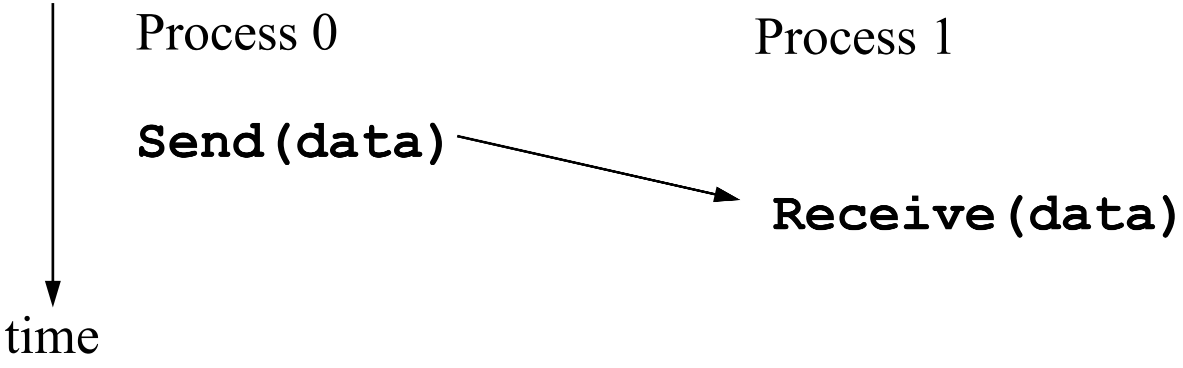

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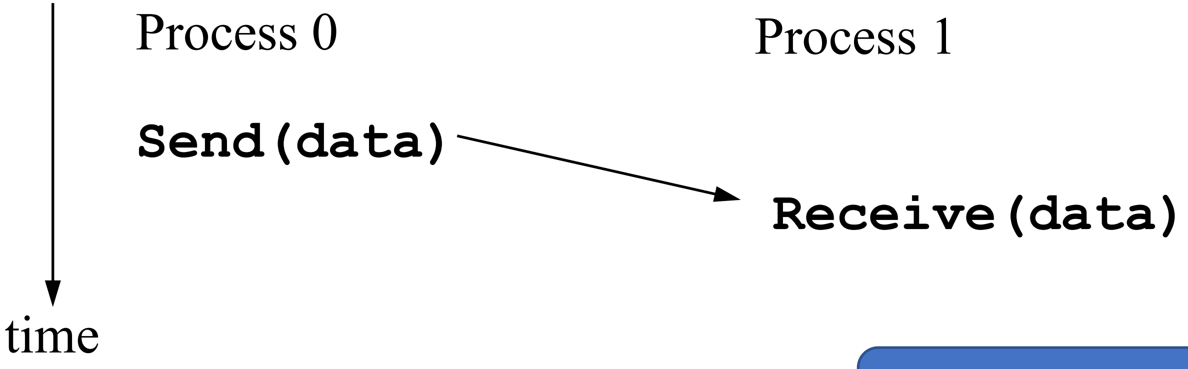

Familiar argument?

One-Sided Operations

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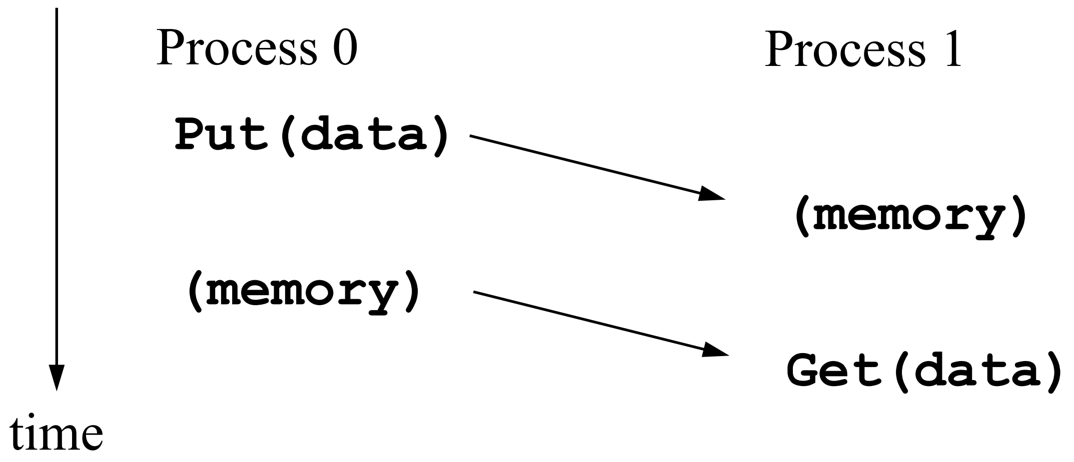
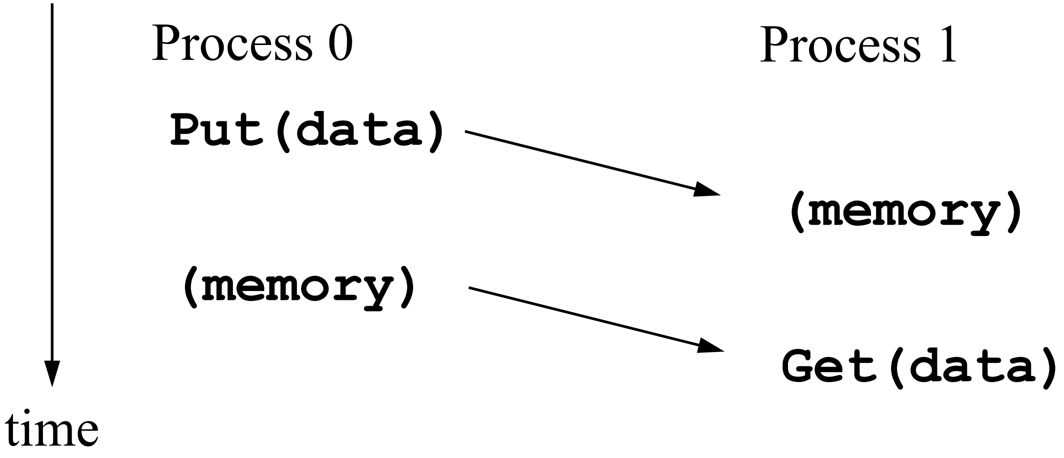


One-Sided Operations

One-sided operations between processes

- Include remote memory reads and writes



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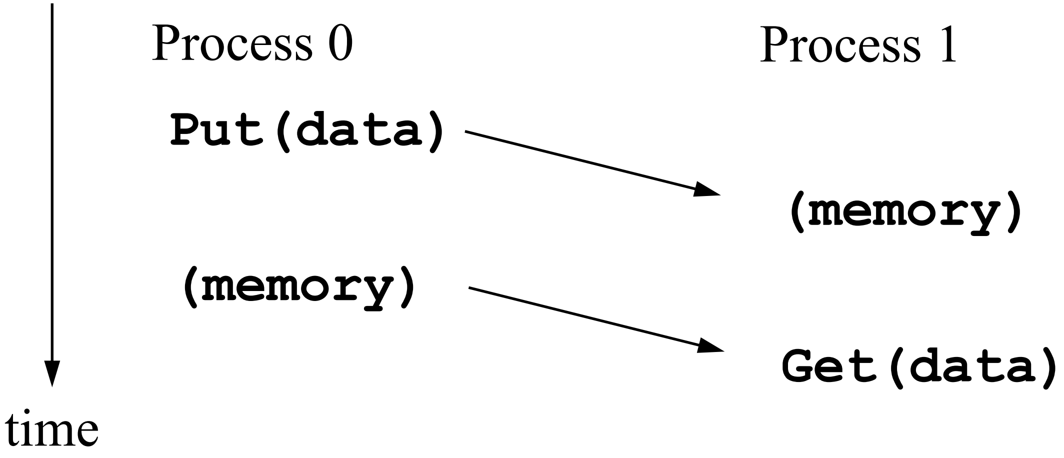

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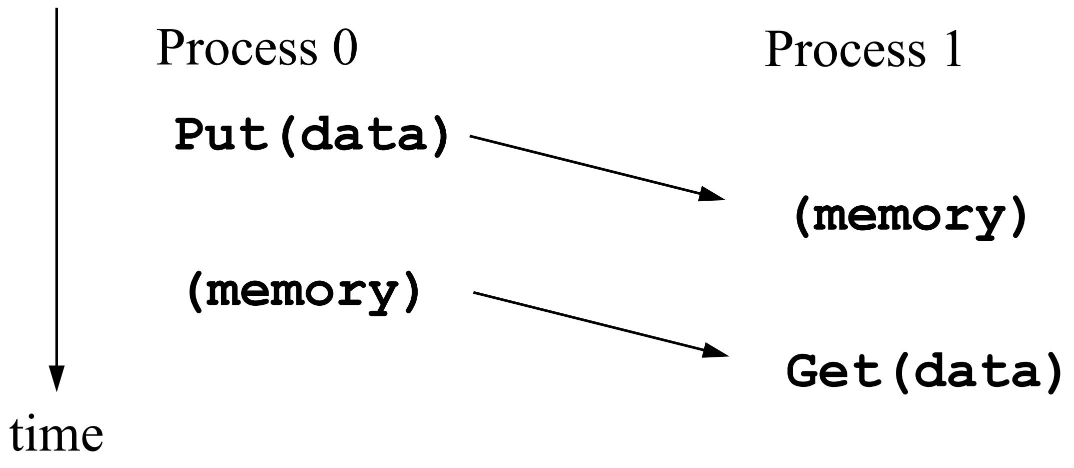

One-Sided Operations

Are 1-sided operations better for performance?

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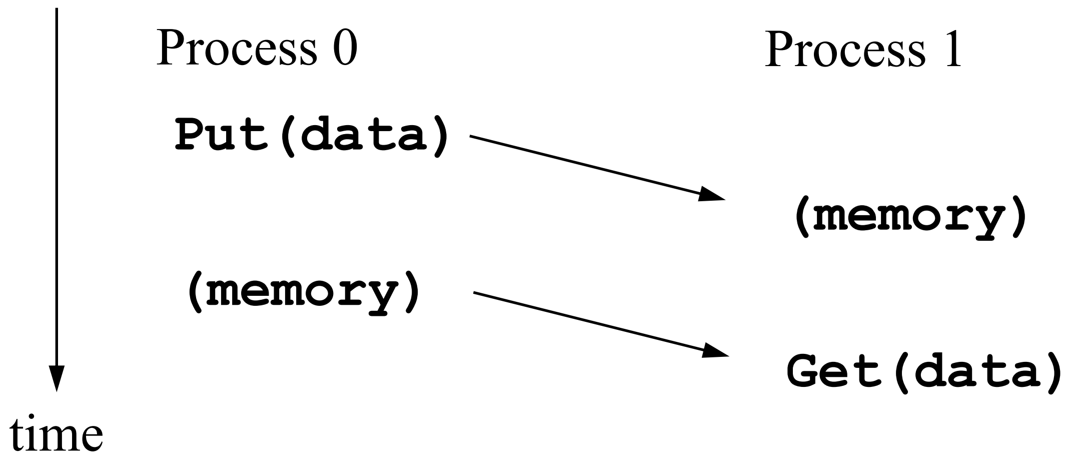

A Simple MPI Program

```
#include "mpi.h"
#include <stdio.h>

int main( int argc, char *argv[] )
{
    MPI_Init( &argc, &argv );
    printf( "Hello, world!\n" );
    MPI_Finalize();
    return 0;
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MPI_Init

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Hardware resources allocated

- MPI-managed ones anyway…

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- Libraries may handle errors differently from applications

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% mpirun -np <procs> a.out

- **For MPICH under Linux**

mpiexec <args>

- Recommended part of MPI-2, as a recommendation
- **mpiexec** for MPICH (distribution from ANL)
- **mpirun** for SGI's MPI

Finding Out About the Environment

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Two important questions that arise in message passing

- How many processes are being use in computation?
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MPI provides functions to answer these questions

- **MPI_Comm_size** reports the number of processes
- **MPI_Comm_rank** reports the rank
  - number between 0 and size-1
  - identifies the calling process

Hello World Revisited

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Comm?
"Communicator"

Basic Concepts

Processes can be collected into *groups*

Each message is sent in a *context*

- Must be received in the same context!

A group and context together form a *communicator*

A process is identified by its *rank*

- With respect to the group associated with a communicator

There is a default communicator MPI_COMM_WORLD

- Contains all initial processes

MPI Datatypes

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An MPI *datatype* is recursively defined as:

- Predefined data type from the language
- A contiguous array of MPI datatypes
- A strided block of datatypes
- An indexed array of blocks of datatypes
- An arbitrary structure of datatypes

MPI Datatypes

Message data (sent or received) is described by a triple

address, count, datatype

An MPI *datatype* is recursively defined as:

- Predefined data type from the language
- A contiguous array of MPI datatypes
- A strided block of datatypes
- An indexed array of blocks of datatypes
- An arbitrary structure of datatypes

There are MPI functions to construct custom datatypes

- Array of (int, float) pairs
- Row of a matrix stored columnwise

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  - MPI provides the representation translation if necessary
- Allows application-oriented layout of data in memory
  - Reduces memory-to-memory copies in implementation
  - Allows use of special hardware (scatter/gather)

MPI Tags

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  - Assist the receiving process in identifying the message
- Messages can be screened at receiving end by specifying specific tag
  - **MPI_ANY_TAG** matches any tag in a receive
- Tags are sometimes called "message types"
  - MPI calls them "tags" to avoid confusion with datatypes

MPI Basic (Blocking) Send

`MPI_SEND (start, count, datatype, dest, tag, comm)`

- The message buffer is described by:
  - **`start`**, **`count`**, **`datatype`**
- The target process is specified by **`dest`**
  - Rank of the target process in the communicator specified by **`comm`**
- Process blocks until:
  - Data has been delivered to the system
  - Buffer can then be reused
- Message may not have been received by target process!

MPI with Only Six Functions

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Many parallel programs can be written using:

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MPI_FINALIZE()

MPI_COMM_SIZE()

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Why have any other APIs (e.g. broadcast, reduce, etc.)?

Point-to-point (send/recv) isn't always the most efficient...

- Add more support for communication

Excerpt: Barnes-Hut

```
int ctr=nLocalOriginal;
int offset=nLocalOriginal-nLocal;
for(i=0;i<worldSize;i++){
if(i==rank){
    MPI_Bcast(s_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,i,MPI_COMM_WORLD);
} else {
    MPI_Bcast(l_particles,N_POS_ELEMS*nLocalMax+1,MPI_DOUBLE,i,MPI_COMM_WORLD);
    for(k=0;k<l_particles[0];k++, ctr++){
    if(l_particles[MASS(k)]<0){
        offset++;
        _nparticles--;
    } else {
        s_particles[PX(ctr)]=l_particles[PX(k)];
        s_particles[PY(ctr)]=l_particles[PY(k)];
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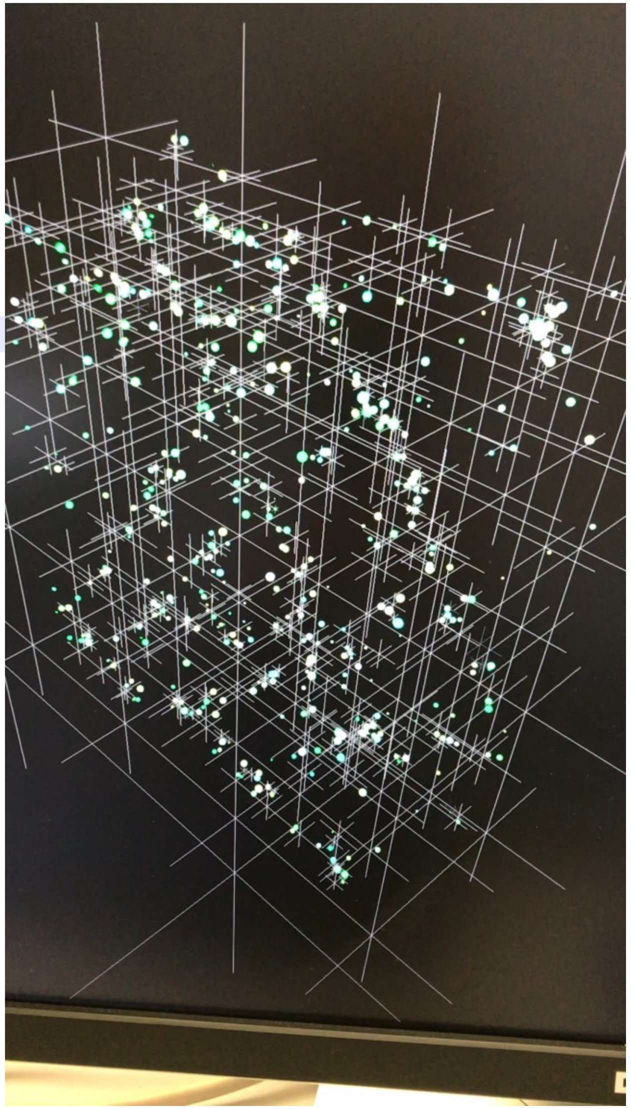

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  - You have irregular or dynamic data relationships
  - You care about performance

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  - You care about performance
- NOT USE
  - You don’t need parallelism at all
  - You can use libraries (which may be written in MPI) or other tools
  - You can use multi-threading in a concurrent environment
    - You don’t need extreme scale