Application Emulators and Interaction with Simulators

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Application Emulators

- Exhibits computational and access patterns that resemble patterns observed in the real application
- Provides a parameterized model of the application
- A simplified version
- A suite of programs

Why do we need application emulators?

- Trace from actual run
  - It is obtained for a single instance of application and machine configuration
  - It is static, it cannot reflect dynamic nature of application
- Running full application on simulator
  - It complicates the task of simulator unnecessarily
  - Execution of real application requires real data
  - Scaling real application for large scale machines may not be possible
- Application emulator
  - It is parameterized, not specific to a single instance of application/machine configuration.
  - It is a program, it can model dynamic nature of application.
  - Level of abstraction can be controlled, it simplifies task of simulator
  - It does not require real data, can be scaled for large machines

Data-intensive Scientific Applications Suite

Titan

- Satellite data processing
- peer-to-peer

Pathfinder

- Satellite data processing
- client-server (separate IO and Compute nodes)

Virtual Microscope

- Microscope image database server
- data server (multiple simultaneous queries), peer-to-peer

Titan: Input Data Structure

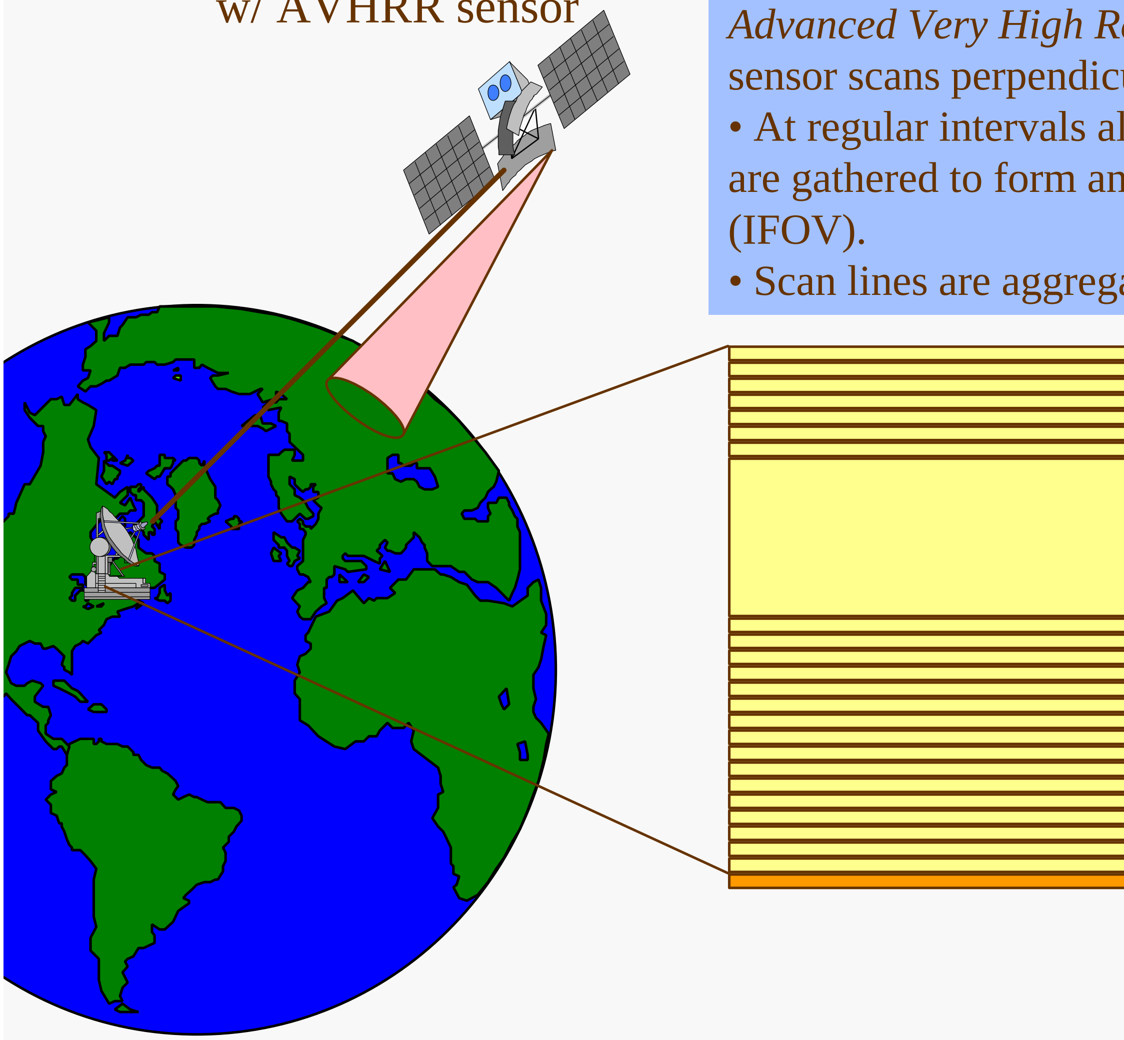
Satellite Data
- Satellite orbits earth in polar orbit
- Each element (IFOV) is associated with a position (in longitude-latitude) and time of recording

Input data is partitioned into data-blocks
- Unit of I/O and communication is a data-block
- Each block contains same number of input elements
- Spatial extent of each block varies
- More overlapping blocks near poles

Data is distributed across disks for I/O parallelism
- Minimax algorithm (Moon et al. 1996) for declustering

Remotely Sensed Data

NOAA Tiros-N
w/ AVHRR sensor



AVHRR Level 1 Data

• As the TIROS-N satellite orbits, the *Advanced Very High Resolution Radiometer* (A sensor scans perpendicular to the satellite's trac

• At regular intervals along a scan line measure are gathered to form an *instantaneous field of v* (IFOV).

• Scan lines are aggregated into Level 1 data set

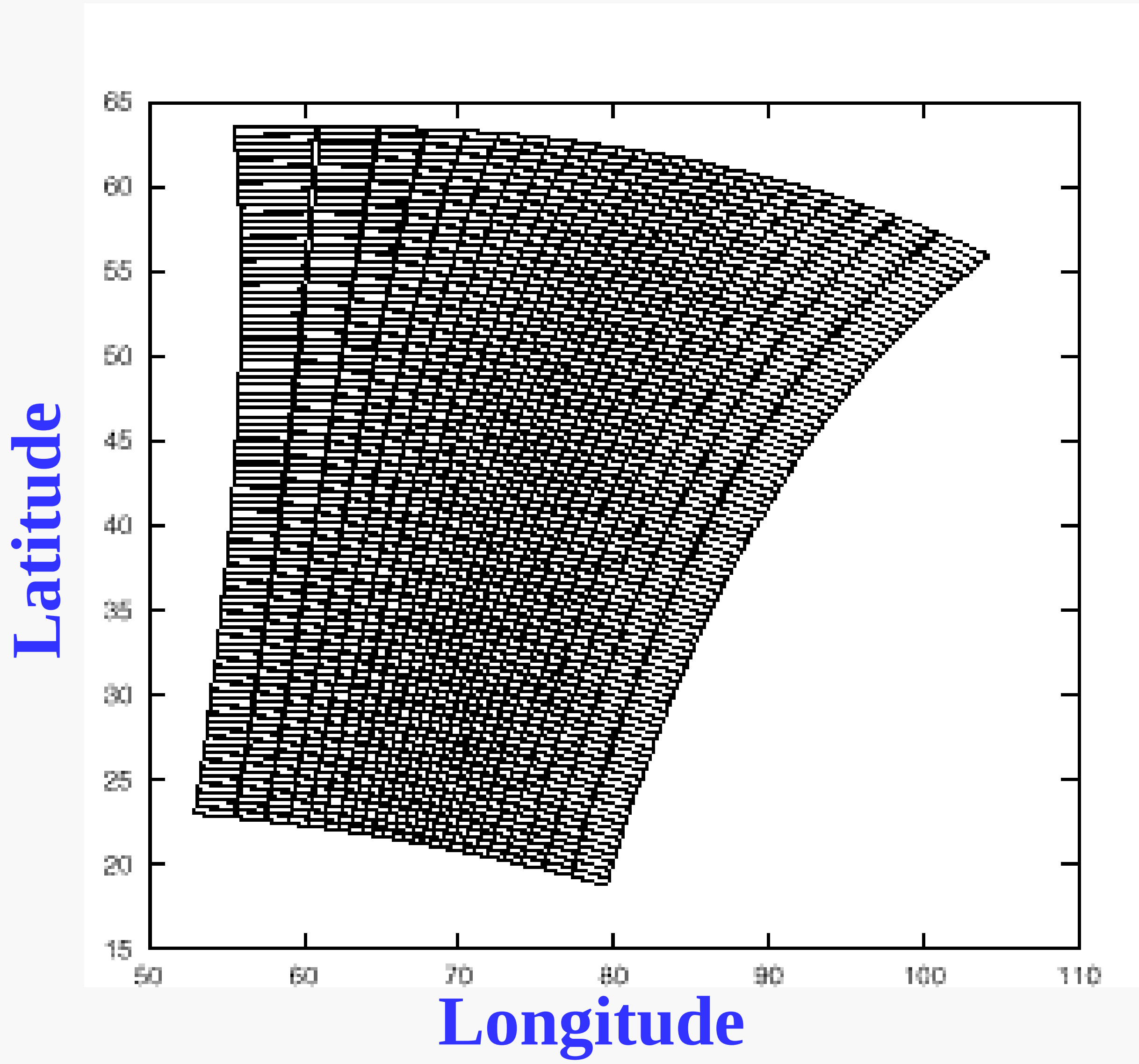
A single file of *Glo Coverage* (GAC) d represents:

• ~one full earth orbit.
• ~110 minutes.
• ~40 megabytes.
• ~15,000 scan lines.

One scan line is 409

Spatial Irregularity

VHRR Level 1B NOAA-7 Satellite 16x16 IFOV blo



Titan: Output Data Structure

2D image

Partitioned into equal size rectangles among processors

Each processor is responsible for processing of blocks that map onto its region

Titan: Processing Loop

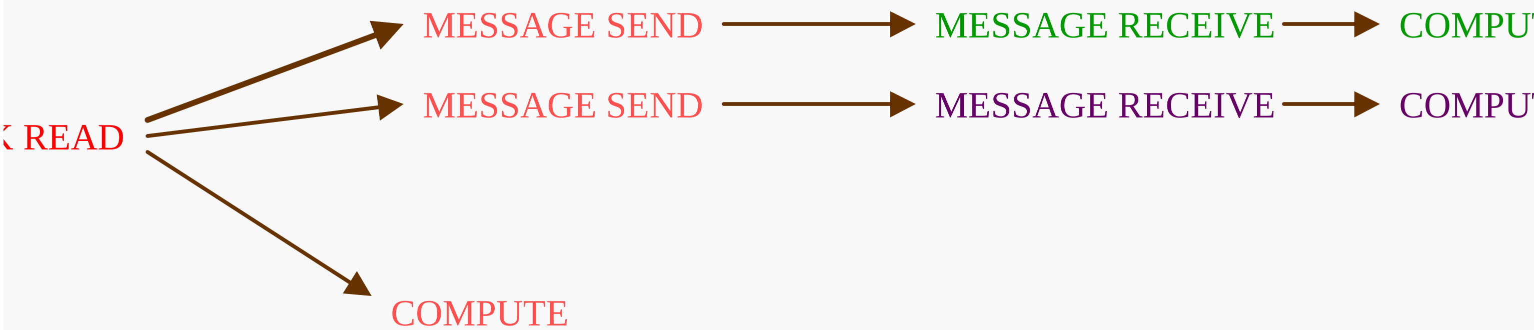
```
While (not done) do
   Issue reads
   Issue receives
   Poll reads
      if (some reads completed) then
         Map data-block to output data
         if (mapped to other processors)
            Issue sends to those processors
         if (mapped to myself)
            Enqueue for processing
   Poll receives
      if (data-block received)
         Enqueue for processing
   Poll sends
   Process a data-block
end while
```

not done when there are
* reads yet to be issued
* pending reads
* receives yet to be issued
* pending receives
* pending sends
* blocks yet to be processed

Processing Loop

* All communication and IO are non-blocking operations
* There are dependencies between operations on a data-bloc

Life cycle of a data-block



An Emulator for Titan

Input Data Structure

- I/O, Communication, Computation patterns

Output Data Structure (Work load partitioning)

- Communication, Computation patterns

Processing Loop

- I/O, Communication, Computation patterns

An Emulator for Titan

Description of the machine

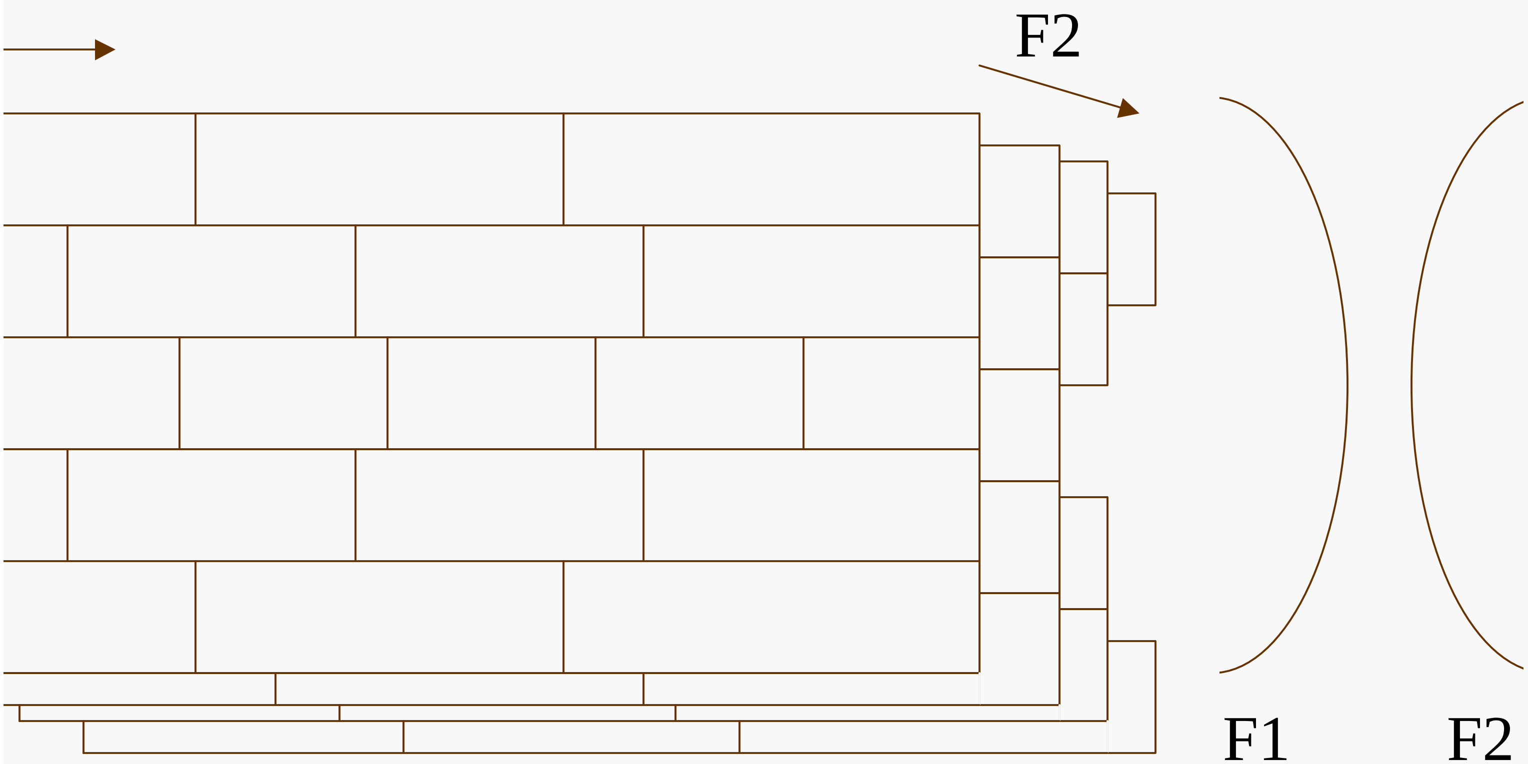
- number of processors and disks
- machine description file (for Petasim)

Input Data Structure

- Controlled generation of data-blocks using functions
- Parameterized generation of blocks
  - number of blocks
  - size of a block
- Simple block-cyclic distribution of blocks to disks

An Emulator for Titan

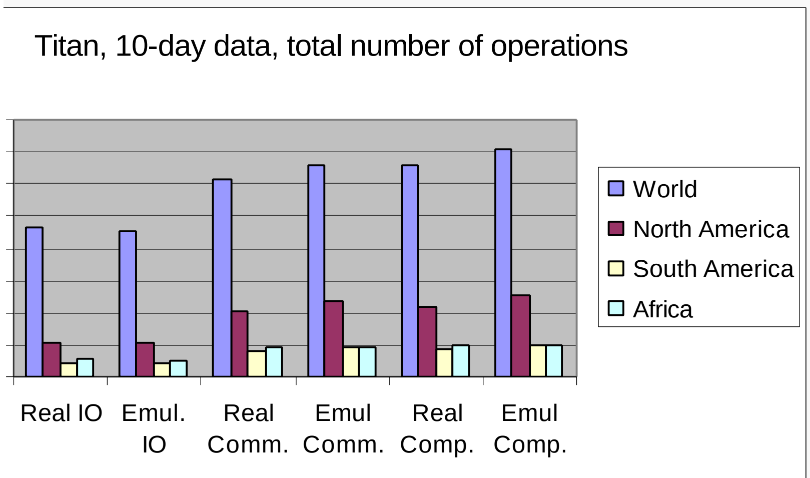
Generation of Input data-blocks

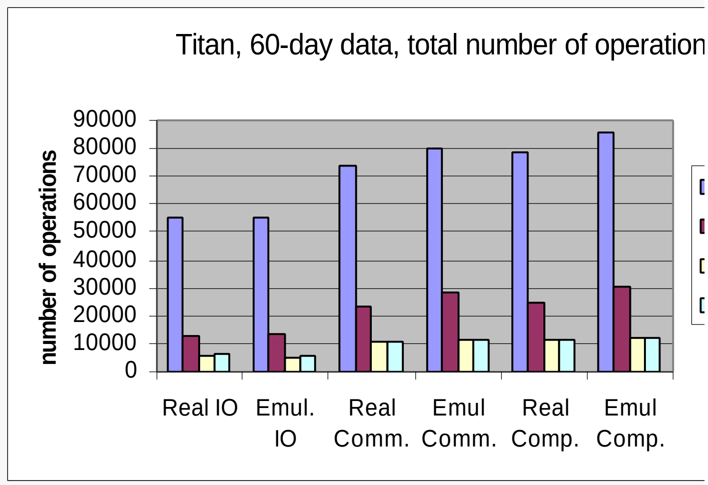


An Emulator for Titan

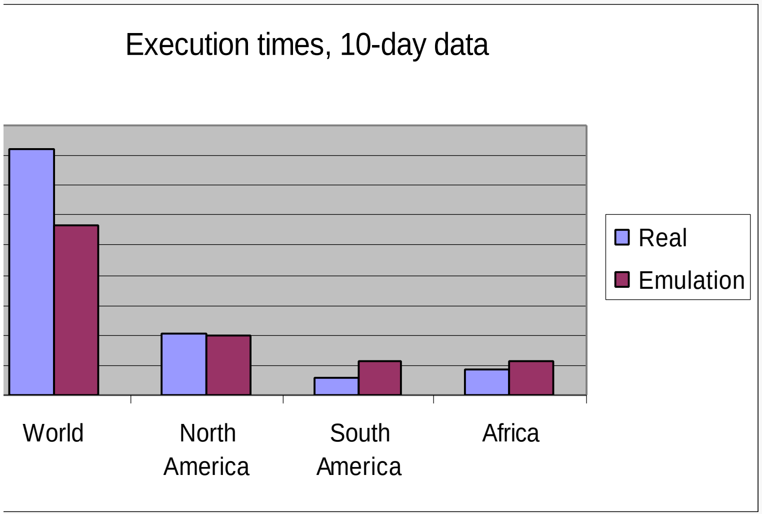
- Output Data Structure
  - Represented by a 2D rectangle
  - Parameterized 2D processor mesh
    - number of processors in x and y dimensions
- Processing Loop
  - Retain non-blocking nature of operations
  - Retain dependencies between operations on a block
  - Parameterization of some operations
    - number of maximum pending reads, receives
    - number of blocks processed per iteration of loop
  - Each block is assumed to take the same amount of time
    - computation time of a block can be changed

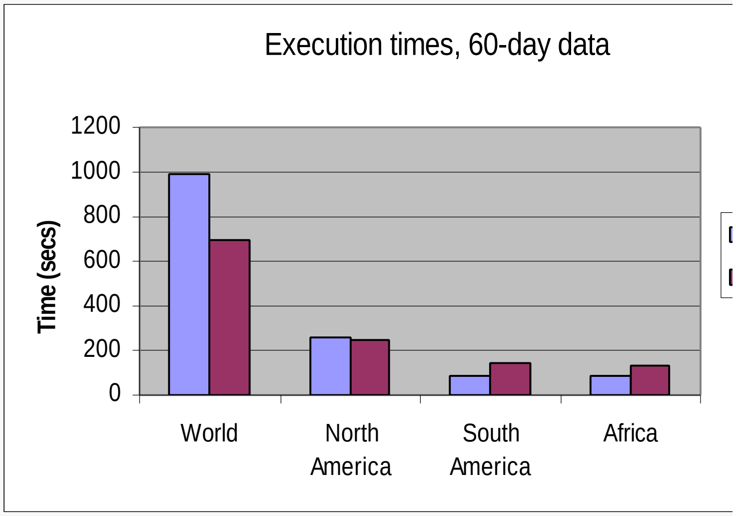
Comparison of Real Application and Emulator





Comparison of Real Application and Emulator





Interaction with Simulators

- Tightly-coupled Simulation
  - Similar to running on real machine
    - a thread is created for each application emulator process
    - emulator performs calls to simulator API for
      - **initiating I/O, communication, and computation operations (events**
      - **checking their completion**
  - Simulator schedules emulator threads to ensure correct logical order of operations
  - Emulator and simulator interacts for each event (e.g., disk read request)
  - Emulator keeps track of dependencies between operations

Interaction with Simulators

Tightly-coupled simulation is not suitable for simulating large scal machines

- Number of emulator threads increases with increasing number of processors
  - Scheduling these threads becomes very costly
- Message and I/O tables for outstanding non-blocking operations become very large
  - Need for large memory to store these tables
  - Very costly to manage these tables
- Each emulator thread has to keep track of non-blocking operations
  - Needs its local data structures (tables) for these operations
  - Replicates the work of simulator.

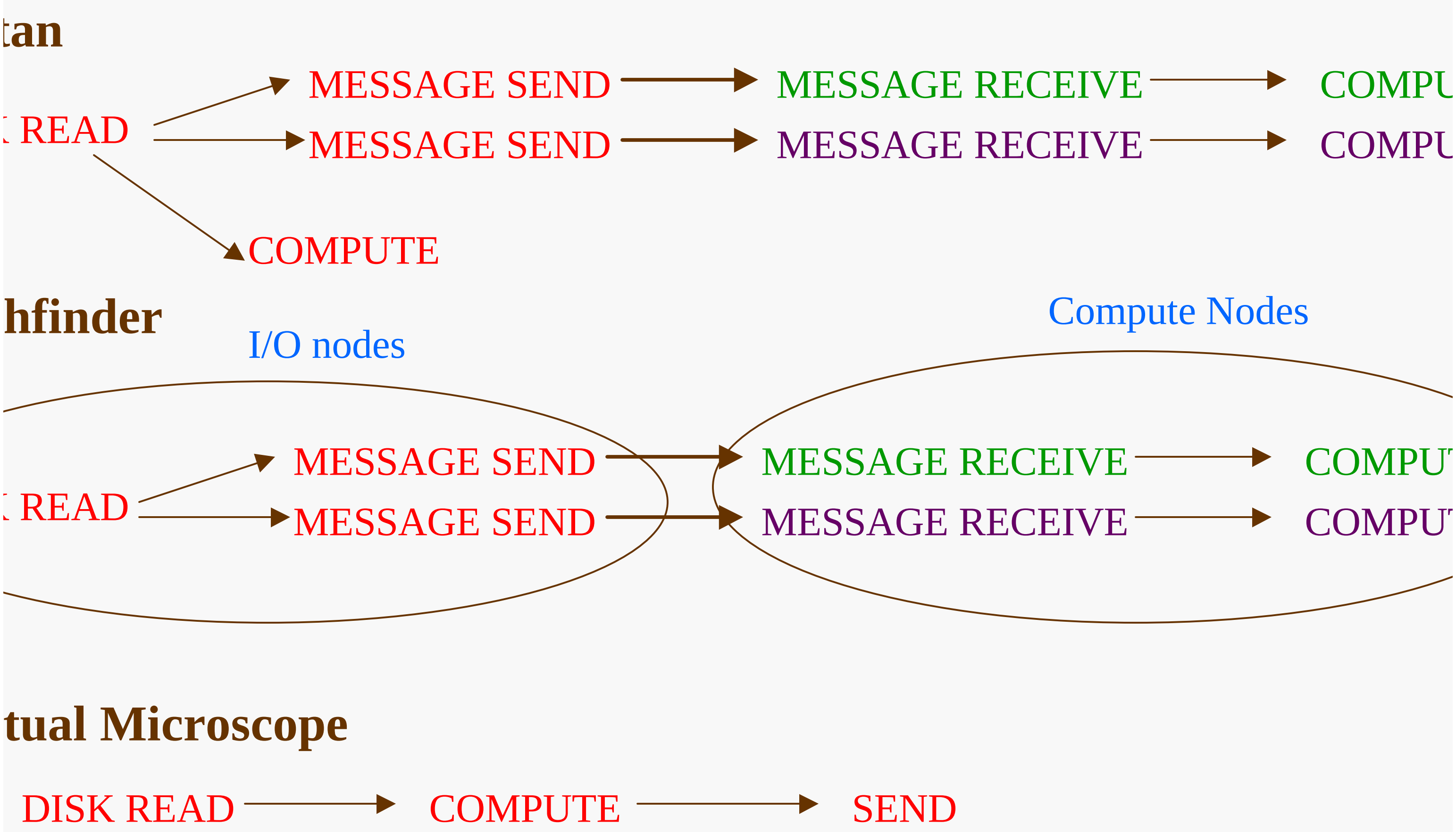
Interaction with Simulators

Loosely-coupled Simulation

- Idea: Embed application processing loop into simulator
  - Dependency information of processing loop is embedded in the simulator
- Emulator and simulator interacts in distinct phases called “epochs’
  - Emulator sends a set of events (for a set of blocks) to the simulator
  - Simulator processes these events
  - Simulator asks for another set of events from emulator
- One simulator thread and one emulator thread

Interaction with Simulators

(Modeling Dependencies: Work Flow Graphs)



Interaction with Simulators

No dependencies between operations
- in sets in different epochs
- on different data-blocks

For each block in a set for each processor, emulator passes to simulatc
- disk id
  - indicates a read operation from that disk
- length of the block
  - used to estimate I/O and communication time
- list of consumers
  - indicates communication (sends and receives)
- computation time of the block

Comparison of Simulation Models

Accuracy comparison of Tightly-Couple Simulation (TC-SIM) and Loosely-Coupled Simulation (LC-SIM)

Emulator	Data set	IBM SP2	TC-SIM	LC-SIM
		Execution	Predicted	Predicted
		Time	Time	Time
Titan	9K blocks	113	105 (7%)	100 (12%)
	27K blocks	347	322 (7%)	306 (12%)
Pathfinder	9K blocks	166	153 (8%)	149 (10%)
	27K blocks	497	467 (6%)	452 (9%)
Virtual Microscope	5K blocks (200 queries)	127	122 (4%)	119 (6%)
	7.5K blocks (400 queries)	243	236 (3%)	234 (4%)

Comparison of Simulation Models

Predicted execution time and simulation time for TC-SIM and LC-SIM
All results are in seconds for Maryland IBM SP2

Emulator	Dataset	P	TC-SIM Predicted Execution	TC-SIM Simulation Time	LC-SIM Predicted Execution	LC-SIM Simulation Time
	27K blocks	32	211	3426	182	6
Titan	55K blocks	64	285	13154	217	14
	110K blocks	128	604	116224	420	28
	55K blocks	32	551	11595	496	22
Pathfinder	110K blocks	64	718	30446	579	57
	220K blocks	128	1020	97992	881	126
	500 K blocks	32	135	7155	118	4
Virtual Microscope	1000K blocks	64	145	14097	126	8
	2000K blocks	128	158	37534	138	17

Conclusions

Emulators for Data-intensive scientific applications

- Simple and parameterized model of applications
- Enables performance prediction studies on large scale machines

Loosely-coupled simulation

- Enables the simulation of large scale machines