Exercises: April 11
PARTITIONING IN MPI
COMMUNICATION AND NOISE AS HPC BOTTLENECK
LOAD BALANCING

DISTRIBUTED OPERATING SYSTEMS, SCALABILITY, SS 2017

Hermann Härtig
Partitioning:
bulk synchronous execution
MPI collectives

Communication and Noise

Load Balancing (MosiX):
migration mechanisms
information dissemination
decision making
- independent OS processes
- bulk synchronous execution (HPC)
  - sequence: compute - communicate
  - all processes wait for all other processes
  - often: message passing for example Message Passing Library (MPI)
- all processes execute same program
- while (true)
  {  work;  exchange data (barrier)}
- common in
  High Performance Computing:
  Message Passing Interface (MPI)
  library
MPI: Message Passing Interface

- Library for message-oriented parallel programming
- **Common but not mandatory**

Programming model:
- Multiple instances of same program
- Independent calculation
- Communication, synchronization
MPI program is started on all processors

- `MPI_Init()`, `MPI_Finalize()`

Communicators (e.g., `MPI_COMM_WORLD`)

- `MPI_Comm_size()`
- `MPI_Comm_rank()`: “Rank” of process within this set

Typed messages

- (Dynamically create and spread processes using `MPI_Spawn()` (since MPI-2))
- Communication
- Point-to-point
- Collectives
- Synchronization
- Test
- Wait
- Barrier

```c
MPI_Bcast(
    void* buffer,
    int count,
    MPI_Datatype datatype,
    int root,
    MPI_Comm comm
)

MPI_ReDuCe(
    void* sendbuf,
    void* recvbuf,
    int count,
    MPI_Datatype datatype,
    MPI_Op op,
    int root,
    MPI_Comm comm
)

MPI_Barrier(
    MPI_Comm comm
)

MPI_Test(
    MPI_Request* request,
    int* flag,
    MPI_Status* status
)

MPI_Wait(
    MPI_Request* request,
    MPI_Status* status
)
```
## BLOCK AND SYNC

<table>
<thead>
<tr>
<th></th>
<th>blocking call</th>
<th>non-blocking call</th>
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</thead>
<tbody>
<tr>
<td><strong>synchronous</strong></td>
<td>returns when message has been delivered</td>
<td>returns immediately, following test/wait checks for delivery</td>
</tr>
<tr>
<td><strong>communication</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>asynchronous</strong></td>
<td>returns when send buffer can be reused</td>
<td>returns immediately, following test/wait checks for send buffer</td>
</tr>
<tr>
<td><strong>communication</strong></td>
<td></td>
<td></td>
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</tbody>
</table>
int rank, total;
MPI_Init();
MPI_Comm_rank(MPI_COMM_WORLD, &rank);
MPI_Comm_size(MPI_COMM_WORLD, &total);

MPI_Bcast(...);
/* work on own part, determined by rank */

if (id == 0) {
    for (int rr = 1; rr < total; ++rr)
        MPI_Recv(...);
    /* Generate final result */
} else {
    MPI_Send(...);
}
MPI_Finalize();
AMDAHLS’ LAW

interpretation for parallel systems:

- **P**: section that can be parallelized
- **1-P**: serial section
- **N**: number of CPUs

\[
\text{Speedup}(P,N) = \frac{1}{1 - P + \frac{P}{N}}
\]
BLOCK SYNCHRONOUS EXECUTION

Communication

Computation

Communication
AMDAHL’S LAW

Serial section: communicate, longest sequential section

Parallel, “Serial”, possible speedup:

- 1ms, 100 μs: 1/0.1 → 10
- 1ms, 1 μs: 1/0.001 → 1000
- 10 μs, 1 μs: 0.01/0.001 → 10
- ...

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WEAK VS. STRONG SCALING

Strong:
- accelerate same problem size

Weak:
- extend to larger problem size
PROBLEMS

- noise
  - execution time jitter
  - interrupt latency
- balance load in case of unbalanced applications
THE NEED FOR BALANCING

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THE NEED FOR BALANCING

work item

Barrier
Use common sense to avoid:

- OS usually not directly on the critical path, BUT OS controls: interference via interrupts, caches, network, memory bus, (RTS techniques)

- avoid or encapsulate side activities

- small critical sections (if any)

- partition networks to isolate traffic of different applications (HW: Blue Gene)

- do not run Python scripts or printer daemons in parallel
- use small kernel to isolate
balancing in systems architecture

- application
- run-time library
- operating system
immediate approach: global run queue
... does not scale

- shared memory only
- contended critical section
- cache affinity
- ...

separate run queues with explicit movement of processes
High Performance Computing

- Operating System / Hardware: “All” participating CPUs: active / inactive

- Partitioning (HW)

- Gang Scheduling (OS)

- Within Gang/Partition: Applications balance !!!
HW PARTITIONS & ENTRY QUEUE

Application

request queue

BATCH SCHEDULER
PROPERTIES HW PARTITIONS

- optimizes usage of network
- takes OS off critical path (busy waiting)
- best for strong scaling
- burdens application/library with balancing
- potentially wastes resources
- current state of the art in High Performance Computing (HPC)
Towards System-Level Balancing

- **Work Item**
- **Time**

**Barrier**
SPLITTING BIG JOBS

overdecomposition & “oversubscription”
Execute small jobs in parallel (if possible)
Programming Model

- many (small) decoupled work items
- overdecompose
  create more work items than active units
- run some balancing algorithm

Example: CHARM ++
- create many more processes
- use OS information on run-time and system state to balance load
- examples:
  - run multiple applications
  - create more MPI processes than nodes (!)
added overhead

- additional communication between smaller work items (memory & cycles)
- more context switches
- OS on critical path
  (for example communication)
required:

- mechanism for migrating load
- information gathering
- decision algorithms

MosiX system as an example

-> Barak’s slides now
MOSIX is a unifying management layer

MOSIX - OS
 Mostly user-level implementation

Applications

Continuous feedback about the state of resources

All the nodes run like one server with many cores
The main software components

1. **Preemptive process migration**
   - Can migrate a running processes anytime
   - Like a course-grain context switch
   - Implication on caching, scheduling, resource utilization

2. **OS virtualization layer**
   - Allows a migrated process to run in remote nodes

3. **On-line algorithms**
   - Attempt to optimize a given goal function by process migration
   - Match between required and available resources
   - **Information dissemination** – based on partial knowledge

**Note:** features that are taken for granted in shared-memory systems, are not easy to support in a cluster
The OS virtualization layer

• A software layer that allows a migrated process to run in remote nodes, away from its home node
  • All system-calls are intercepted
    • Site independent sys-calls are performed locally, others are sent home
  • Migrated processes run in a sandbox

• Outcome:
  • A migrated process seems to be running in its home node
  • The cluster seems to the user as one computer
  • Run-time environment of processes are preserved - no need to change or link applications with any library, copy files or login to remote nodes

• Drawback: increased (reasonable) communication overhead
Process migration - the home node model

- Process migration – move the process context to a remote node
- System context stay at “home” thus providing a single point of entry
- Process partition preserves the user’s run-time environment
- Users need not care where their process are running
FORK IN MOSIX

Deputy

Remote

-establish a new link

Deputy(child)

Remote(child)

fork() syscall request

Reply from fork()

Reply from fork()
PROCESS MIGRATION IN MOSIX

**Process migdaemon**

1. **Remote fork()**
2. Send state, memory maps, dirty pages
3. ack
4. Transition
5. Finalize migration
6. Ack
7. Migration completed
8. Ack

**Deputy**
Distributed bulletin board

• An n node cluster/Cloud system
  – Decentralized control
  – Nodes can fail at any time
• Each node maintains a data structure *(vector)* with an entry about selected (or all) the nodes
• Each entry contains:
  – State of the resources of the corresponding node, e.g. load
  – Age of the information (tune to the local clock)
• The vector is used by each node as a distributed bulletin board
  – Provides information about allocation of new processes
CENTRALIZED GLOBAL STATE
DECENTRALIZED GLOBAL STATE

Node 1

Node 2

..

Node n
DECENTRALIZED GLOBAL STATE

Node 1

Node 2

Node n

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GOSSIP

Node 1

Node 2

...

Node n
When

**M:** load difference discovered
anomaly discovered
anticipated

Where

**M:** memory, cycles, comm
consider topology
application knowledge

Which

**M:** past predicts future
application knowledge
Load balancing algorithms

- **When** - Load difference between a pair of nodes is above a threshold value
- **Which** - Oldest process (assumes past-repeat)
- **Where** - To the known node with the lowest load
- **Many other heuristics**

- **Performance**: our online algorithm is only ~2% slower than the optimal algorithm (which has complete information about all the processes)
Memory ushering

- **Heuristics:** initiate process migration from a node with no free memory to a node with available free memory
- **Useful:** when non-uniform memory usage (many users) or nodes with different memory sizes
- **Overrides load-balancing**

- Recall: placement problem is NP-hard
Memory ushering algorithm

- **When** - free memory drops below a threshold
- **Where** - the node with the lowest load, to avoid unnecessary follow-up migrations
- **Which** - smallest process that brings node under threshold
- To reduce the communication overhead
- memory
- cpu load
- IPC
SOME PRACTICAL PROBLEMS

- flooding
  all processes jump to one new empty node
  => decide immediately before migration commitment
  extra communication, piggy packed

- ping pong
  if thresholds are very close, processes moved back and forth
  => tell a little higher load than real
Scenario:
compare load on nodes 1 and 2
node 1 moves process to node 2

Solutions:
add one + little bit to load
average over time

Solves short peaks problem as well
(short cron processes)
- execution/communication time jitter matters (Amdahl)
- HPC approaches: partition ./ balance
- dynamic balance components: migration mechanism, information bulletin, decision: which, when, where