Load Balancing & Termination
Load Balancing

• Want all processors to operate continuously to minimize time to completion.

• Load balancing determines what work will be done by which processor.
  – Static
  – Dynamic
Static Load Balancing

- Approaches already discussed:
  - Round Robin
  - Random
  - Recursive Bisection
  - Simulated Annealing
  - Genetic Algorithm
Static Load Balancing

- Bin Packing for Homogeneous Systems
  - P boxes of equal size
  - Minimize the size of the boxes, s.t.
    - every piece of work goes in one and only one box
    - the work in any given box will be assigned to one processor
    - put work that requires the most communication on the same processor if possible
Let’s take a very simple example
– 2 homogeneous processors
– 8 homogeneous meshes with sizes
  • \(15\times10\)
  • \(11\times3\)
  • \(10\times10\)
  • \(8\times10\)
  • \(9\times9\)
  • \(8\times9\)
  • \(7\times7\)
  • \(6\times6\)

How close can we come to perfect load balance?
Static Load Balancing

• Extend our example w/communication
  – 2 homogeneous processors
  – 8 homogeneous meshes with sizes
    • 15x10
    • 11x3
    • 10x10
    • 8x10
    • 9x9
    • 8x9
    • 7x7
    • 6x6

• Does the communication change how good we can make our load balance?
Static Load Balancing

- Extend example w/ more communication
  - 2 homogeneous processors
  - 8 homogeneous meshes with sizes
    - 15x10
    - 11x3
    - 10x10
    - 8x10
    - 9x9
    - 8x9
    - 7x7
    - 6x6

- Does the communication change our total runtime and/or balance?

Lecture 7 – Load Balancing and Termination Detection
Static Load Balancing

- Extend example w/more communication
  - 2 homogeneous processors
  - 8 homogeneous meshes with sizes
    - 15x10
    - 11x3
    - 10x10
    - 8x10
    - 9x9
    - 8x9
    - 7x7
    - 6x6

- Here the communication changed our total runtime and/or balance.

Lecture 7 – Load Balancing and Termination Detection
Static Load Balancing

• Bin Packing for Heterogeneous Systems
  – P boxes of variable size representing the capability of the associated processor relative to the total capability of the system
  – Minimize the imbalance, s.t.
    • every piece of work goes in one and only one box
    • put work that requires the most communication on the same processor if possible
    • each box is the same % full
Static Load Balancing

• Let’s extend our example
  – 2 heterogeneous processors
  – 8 homogeneous meshes with sizes
    • 15x10
    • 11x3
    • 10x10
    • 8x10
    • 9x9
    • 8x9
    • 7x7
    • 6x6

• How do heterogeneous processors change what we do?
Static Load Balancing

- Let’s extend our example
  - 2 homogeneous processors
  - 8 heterogeneous meshes with sizes
    - 15x10
    - 11x3
    - 10x10
    - 8x10
    - 9x9
    - 8x9
    - 7x7
    - 6x6

- How do heterogeneous meshes change what we do?
Static Load Balancing

• Let’s extend our example
  – 2 heterogeneous processors
  – 8 heterogeneous meshes with sizes
    • 15x10
    • 11x3
    • 10x10
    • 8x10
    • 9x9
    • 8x9
    • 7x7
    • 6x6

• How do heterogeneous meshes and processors change what we do?
Static Load Balancing

• Problems with Static Load Balancing
  – How do we know for sure what the computation per mesh element is?
  – How do we know for sure what the capabilities of each processor will be?
  – How do we know what the load on each processor will be (shared resources)?
  – Similar questions for the communication...

Given these questions may be impossible to answer for some problems, we move to dynamic load balancing.
Dynamic Load Balancing

• Approaches to Dynamic Load Balance
  – Centralized – a master process hold the collection of tasks to perform and determines when the job is complete
  – Distributed – the tasks are distributed and the decision process for determining termination is distributed
Dynamic Load Balancing

- Centralized Dynamic Load Balance

How can we improve on this process?
Dynamic Load Balancing

• Distributed Dynamic Load Balance

How can we improve on this process?
Dynamic Load Balancing

- Distributed Dynamic Load Balance
  - processes transferring tasks
Dynamic Load Balancing

- Distributed Dynamic Load Balance – processes transferring tasks – How selected?
Dynamic Load Balancing

- Distributed Dynamic Load Balance
  - processes transferring tasks – How selected?

Lecture 7 – Load Balancing and Termination Detection
Dynamic Load Balancing

- Distributed Dynamic Load Balance
  - Multiple threads for
Distributed Termination

• Recognition of termination conditions for distributed computations is more difficult than sequential termination.

• Conditions [Bertsekas & Tsitsiklis, 89]
  – local termination reached by all
  – no communication in progress
Distributed Termination

- Bertsekas & Tsitsiklis
Distributed Termination

• Single-Pass Ring Termination
Distributed Termination

- Dual-pass Ring Termination
  – Dijkstra, Feijen, and Gasteren 1983
Distributed Termination

- Dual-pass Ring Termination
  – Dijkstra, Feijen, and Gasteren 1983
Distributed Termination

• Fixed Energy Termination
  – Start with all energy assigned to the master
  – Send a bit of energy with each task assigned
  – Return the energy when the task is finished
  – When all energy is returned to the master and it has no more work to farm out, termination has been reached.
Program Paradigms

Static Load Balancing
Dynamic Load Balancing
Distributed Termination Detection Algorithms
Program Paradigms
Summary

C C C C ...

Synchronous Interaction

C C C C ...

Synchronous Interaction

ideal
Program Paradigms

Synchronous Interaction

C C C … C

C C C … C

Synchronous Interaction

Lecture 7 – Load Balancing and Termination Detection
Program Paradigms

- Divide and Conquer

Lecture 7 – Load Balancing and Termination Detection
Program Paradigms

Load Balancing
Static Load Balancing
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Program Paradigms
Summary

Lecture 7 – Load Balancing and Termination Detection
Program Paradigms

P

Q

R

...

Z

ideal
Program Paradigms

P → Q → R → Z

Lecture 7 – Load Balancing and Termination Detection
Program Paradigms

Master Slave

Master

S S S S

ideal

Load Balancing
Static Load Balancing
Dynamic Load Balancing
Distributed Termination Detection Algorithms
Program Paradigms
Summary
Program Paradigms

Master

S

S

S

real

Lecture 7 – Load Balancing and Termination Detection
Program Paradigms

Work Pool

P
Q
R
Z

ideal
Program Paradigms

Load Balancing
Static Load Balancing
Dynamic Load Balancing
Distributed Termination Detection Algorithms
Program Paradigms
Summary

real

Work Pool

P
Q
R
...
Z

Lecture 7 – Load Balancing and Termination Detection
Summary

• Load Balancing
  – Centralized
  – Distributed

• Termination

• Paradigms
  – phase
  – pipelined
  – master slave
  – work pool