LoPC: Modeling Contention in Parallel Algorithms

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June 20, 1997
Goal:

- Parallel Program Analysis Tools
  - LogP: Great for Predictable Communication
  - LoPC: Irregular Communication Patterns
Problem:

- Pattern Unknown Until Runtime
- Communication is Randomized: Contention
Solution:

- Extend LogP
- AMVA: Queueing Model that Handles Random Behavior
- Simple: Produces Design Rules
Result:

- Tool for Analyzing Irregular Communication
- Rules of Thumb:
  - Homogeneous All-to-Any Communication
  - Client-Server
Roadmap

- LogP Model
- LoPC Model
- Example
- Rules of Thumb
Architectures

- Active Messages
- Infinite Queues
- Contention Free Network
- End-point Contention Only
The LogP Model

- **L**: Latency
- **o**: overhead
- **g**: gap
- **P**: Processors

- **W**: Work per Message
- **n**: Total number of Messages
The LoPC Model

- LogP - g + end-point Contention
- Messages arrive while working
- Messages compete for processor resources
- Calculate contention (C)
Mean Value Analysis

- Find Contention from \( L, o, P, W \) and \( n \)
- Numerical Solution

\[
X = \frac{P}{R}, \quad Q_k = VXR_k, \quad U_q = VXo,
\]

\[
R_q = o(1 + Q_q + Q_y),
\]

\[
R_y = o(1 + Q_q), \quad R_w = \frac{W + oQ_q}{1-U_q},
\]

\[
R = R_w + L + R_q + L + R_y
\]
Irregular Algorithms

- Examples:
  - Sparse Matrix
  - Radix and Quicksort
  - Hash Join
  - Workpiles
  - VLSI Place and Route (Graphs)
- Regular algorithms are also stochastic!
- Computation is data dependent
- Message destination is data dependent
Example: Sparse Matrix

- \( W = \frac{P}{P-1} \) ops per comm step
- \( n = \frac{b(P-1)}{P} \) comm steps per processor
Sparse Matrix

- Calculate C from L, o, P, W and n
- Contention Amplifies Communication Costs
- LoPC Pessimistic
Rules of Thumb

- Simplify
- Gain Intuition

General Rules

\[
X = \frac{P}{R}, \quad Q_k = VXR_k, \quad U_q = VXo,
\]

\[
R_q = o(1 + Q_q + Q_y),
\]

\[
R_y = o(1 + Q_q), \quad R_w = \frac{W + oQ_q}{1 - U_q},
\]

\[
R = R_w + L + R_q + L + R_y
\]
All-to-All Communication

- Examples:
  - Sparse Matrix
  - Radix Sort
  - Hash Join

- Assume Homogeneous System

- Find Limits on Fixed Point of Solution:
  \[ 0 < C < 1.46 \approx \]

- Rule of thumb: \[ C \approx 1.0 \times o \]
What’s going on?

- Fine-grain: each message waits time $o/2$
- Variability makes problem worse.
- Application “self regulates”
Coarse Grain

- Each message interrupts real work adding time $O$
Client-Server Communication

- Examples:
  - Workpile
  - Branch and Bound
- Divide Nodes into Clients and Servers
- Optimal Number of Servers when \( Q_s = 1 \)

- Rule of Thumb: \( P_s = \frac{2oP}{W + 2L + 5o} \)
Conclusion

- Contention: Up to 1/3 of Execution Cost
- More if Communication is Unbalanced
- LoPC: A Tool for Analyzing Contention
  - Simple
  - Accurate
- Rules for Simple Irregular Communication Patterns