Process Assignment, Scheduling and Load Balancing

Study-Ready Notes

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Contents

1 Introduction to Process Assignment and Scheduling

1.1 Basic Concepts

- **Process Assignment**: Mapping processes to processing elements (PEs)
  - Considers: Process characteristics, Hardware/Software characteristics
  - Answers the question: **Where?**
- **Scheduling**: Determining when to start executing each task
  - Types: Undirected, Directed
  - Answers the question: **When?**

[Summary] Process assignment determines where processes run, while scheduling determines when they execute. Both consider system and process characteristics for optimal performance.

1.2 Programming Models

- **Definition**: Abstractions of CPU hardware, memory, and communication architectures
- **Types**: SPMD (Single Program Multiple Data), MPMD (Multiple Program Multiple Data), Shared Memory, Message Passing
- **Selection Criteria**:
  - Application problem characteristics
  - Available parallel computer architecture
  - Knowledge of parallel algorithms and programming languages

[Summary] Programming models provide abstractions for parallel computing, with selection depending on application needs and available hardware.

2 Critical Factors in Parallel Computing

2.1 Granularity

- **Definition**: Ratio of computation to communication
- **Coarse vs Fine Granularity**:
  - Coarse: Large computational work between communication events
  - Fine: Frequent communication with smaller computation chunks
- **Impact**: Higher computation/communication ratio → better speedup and efficiency

2.2 Overheads

- **Types**:
  - Synchronization costs
  - Data communication costs
- **Significance**: Overheads reduce effective parallel speedup

2.3 Scalability

- **Definition**: Ability to maintain performance improvement with increasing processors
- **Influencing Factors**:
  - Memory-CPU bandwidth
  - Network communication capabilities
  - Application algorithm design
  - Programming language characteristics
  - Process assignment strategy

[Summary] Granularity, overheads, and scalability are critical factors affecting parallel performance, with granularity balancing computation and communication trade-offs.

3 Processor and System Characteristics

3.1 Homogeneous vs Heterogeneous Systems

- **Homogeneous Processors**:
  - All processors identical in type and capability
  - Uniform computing and communication costs
- **Heterogeneous Processors**:
  - Processors with varying capabilities (speed, resources, software)
  - Different computing and communication costs
  - May require specific processors for certain processes

3.2 Network Characteristics

- **Homogeneous/Heterogeneous Networks**:
  - Communication bandwidth may vary
  - Considerations: Mobility, disconnection issues

3.3 Cost Modeling

- **Total Cost Formula**:

$$\text{Total Cost} = \text{Computing Costs} + \text{Communication Costs}$$

- **Example Calculation**:
  - Given process costs on different processors
  - Communication cost between processors = 1 unit
  - Assignment: (B,C,D) $\rightarrow$ P1; (A,E,F) $\rightarrow$ P2
  - Total Cost = Sum of computation costs + communication costs

[Summary] System heterogeneity affects assignment decisions, with total cost being the sum of computation and communication expenses.

4 Problem and System Knowledge Requirements

4.1 Problem Analysis

- **Focus Areas**:
  - Parallelize most time-consuming processes
  - Avoid parallelizing trivial processes
  - Identify bottlenecks: I/O, data dependencies

4.2 System Analysis

- **Processor Characteristics**:
  - Speed, memory capacity
- **Topology Types**:
  - Mesh, Tree, Hypercube, 3-D Mesh
- **Communication Patterns**:
  - Processor-Processor
  - Processor-Memory
  - Memory-Memory

5 Decomposition Strategies

5.1 Domain Decomposition

- **Approach**: Divide data into discrete chunks
- **Applications**: Matrix operations, Image processing
- **Goal**: Maintain high $\frac{\text{cost of computing (R)}}{\text{cost of communication (C)}}$ ratio
- **Considerations**: Match system (R,C) with application (r,c)

5.2 Functional Decomposition

- **Approach**: Assign different functions to different processors
- **Applications**: Signal processing (pipelined filter stages)
- **Key Principle**: Maintain matching R/C to r/c ratios for improved parallelism

[Summary] Domain decomposition partitions data, while functional decomposition partitions functions, both aiming to optimize computation-communication ratios.

6 Process Assignment and Scheduling Types

6.1 Static Scheduling

- **Characteristics**:
  - Problem and process complexities known *a priori*
  - Fixed assignments determined before execution
- **Applications**: Traditional parallel systems with predictable workloads

6.2 Dynamic Scheduling

- **Characteristics**:
  - Processor availability changes over time
  - Adapts to system state changes
  - Combined with process migration and load balancing
- **Applications**:
  - Cloud systems (shared resources)
  - Mobile systems (mobility, battery constraints)

[Summary] Static scheduling works with known parameters, while dynamic scheduling adapts to changing system conditions.

7 Process Scheduling Approaches

7.1 Centralized vs Decentralized

- **Centralized Scheduling**:
  - Single controller makes all decisions
  - Pros: Consistent, global view
  - Cons: Single point of failure, scalability issues
- **Decentralized Scheduling**:
  - Distributed decision making
  - Pros: Scalable, fault-tolerant
  - Cons: Coordination overhead, potential inconsistencies

7.2 Primary Issues: Problem Perspective

- **Workload Distribution**:
  - Distributing jobs and metadata
  - Queue length management
- **Session State Management**:
  - Node stickiness (affinity)
  - Cost of task reallocation
  - Session state distribution

7.3 Primary Issues: System Perspective

- **Node Selection Policies**:
  - Random selection
  - Round Robin
  - Shortest queue
  - Threshold-based (queue length ¿ threshold)
- **Workload Metrics**:
  - Queue Length
  - CPU Utilization
  - Response Time, Capacity, Network latency
  - Probe limit

8 Optimal Scheduling Analysis

8.1 Mathematical Formulation

- **System Model**:
  - N tasks: $p_1, p_2, p_3, \ldots, p_N$
  - 2 processors: A and B
  - Assignment: A: $p_1, p_2, \ldots, p_k$; B: $p_{k+1}, p_{k+2}, \ldots, p_N$
- **Cost Components**:
  - Computation cost for process $p_i = r_i$
  - Communication cost between p_i and $p_j = c_{i,j}$ if on different processors
  - Communication cost $= 0$ if on same processor

8.2 Cost Analysis

- **Total Cost Formula**:

$$\text{Total Cost} = r \times \max(k, N-k) + c \times [k \times (N-k)]$$

- **Special Cases**:
  - All processes on one processor ($k = N$):

$$\text{Cost} = r \times N$$

  - Equal division ($k = N/2$):

$$\text{Cost} = \frac{r \times N}{2} + c \times \left(\frac{N}{2} \times \frac{N}{2}\right) = \frac{1}{2}\left(r \times N + \frac{c \times N^2}{2}\right)$$

8.3 Parallelization Decision

- **Condition for Parallelization**:

$$r \times N > \frac{1}{2}\left(r \times N + \frac{c \times N^2}{2}\right)$$

  Simplifies to:

$$\frac{r}{c} > \frac{N}{2}$$

- **Decision Rule**:
  - Equal distribution if $\frac{r}{c} > \frac{N}{2}$
  - Use single processor if $\frac{r}{c} \leq \frac{N}{2}$
  - Decision independent of number of processors

8.4 Assumptions and Limitations

- **Key Assumptions**:
  - Total communication among all processes
  - No overlap between computation and communication
  - All processes communicate with each other
- **Real-world Considerations**:
  - Subset of processes communicate
  - Computation and communication can often overlap

[Summary] Optimal scheduling depends on the computation-to-communication cost ratio, with parallelization beneficial only when $r/c > N/2$.

9 Clustering in Process Scheduling

9.1 Clustering Concept

- **Objective**: Group processes to minimize communication costs
- **Computation Cost**: $\sum_{i=1}^{n} r_i$
- **Communication Cost**: $\sum c_{in} + \sum c_{out}$

9.2 Clustering Strategies

- **Input/Output Focus**:
  - Consider incoming and outgoing communication costs
  - Balance computation and communication within clusters

10 Dynamic Load Balancing

10.1 Basic Concepts

- **Definition**: Equitable distribution of load among processors
- **Goal**: Minimize difference between most heavily and lightly loaded processors
- **Key Principle**: Adjust based on monitored system state

10.2 Dynamic Scheduling Algorithms

- **Sender-Initiated Algorithms**:
  - Transfer policy: When queue length exceeds threshold
  - Selection policy: Which process to transfer
  - Location policy: Cost and distance considerations
- **Receiver-Initiated Algorithms**:
  - Triggered when queue length falls below threshold

10.3 Dynamic System Challenges

- **Sources of Dynamism**:
  - Uncertainty in task execution times
  - Dynamic task arrival and departure
  - Changing processor availability
  - Network condition variations
  - Task priority changes
  - Processor and network faults
- **Exacerbating Factors**:
  - Cloud systems (resource sharing)
  - Mobile systems (mobility, energy constraints)

[Summary] Dynamic load balancing adapts to changing system conditions using sender or receiver initiated approaches to maintain equitable load distribution.

11 Load Balancing Methods and Challenges

11.1 Approaches to Load Balancing

- **Centralized vs Decentralized**:
  - Centralized: Single controller, less scalable
  - Decentralized: Distributed control, more scalable
- **Information Collection**:
  - How to obtain processor state information
  - Centralized vs decentralized collection
  - Periodic vs event-driven updates
  - Threshold-based monitoring

11.2 Key Questions in Load Balancing

- **Transfer Policy**: Whether to move processes
- **Location Policy**: Where to move processes
- **Process Selection**: Which processes to move
- **Decision Architecture**: Centralized or distributed control

11.3 Cost Considerations

- **Processing Overhead**:
  - Data collection for load monitoring
  - Decision making computations
- **Network Overhead**:
  - Distribution of load information
  - Process migration costs
  - Job redistribution

12 Static vs Dynamic Load Balancing

12.1 Static Load Sharing

- **Characteristics**:
  - Fixed policy, no adaptation to system state
  - Simple, low cost implementation
  - Handles session state easily
  - Cannot adjust to dynamic changes

12.2 Dynamic Load Balancing

- **Advantages**:
  - Adapts to changing system conditions
  - Better resource utilization
  - Handles unpredictable workloads
- **Disadvantages**:
  - Complex implementation
  - Significant overhead costs
  - Session state management challenges

13 Process Migration

13.1 Migration Process

- **Steps**:
  - Migration request initiation
  - Process suspension on source host
  - State transfer to destination host
  - Process resumption on destination
  - File server coordination

13.2 Migration Scenarios

- **Work Stealing**:
  - Idle processor seeks work from busy ones
  - ”No more work → Find work elsewhere”
- **Load Distribution**:
  - Balance load across multiple processors
  - Handle processor saturation scenarios

14 Distributed Scheduling Framework

14.1 System Components

- **Load Information Management**:
  - Collects local node load information
  - Disseminates information to other nodes
- **Distributed Scheduling**:
  - Makes migration decisions
  - Determines when, where, and which processes to migrate
- **Migration Mechanism**:
  - Executes the actual process transfer

14.2 Implementation Considerations

- **Local Information Collection**: Monitoring node status
- **Information Dissemination**: Sharing load data
- **Migration Directives**: Decision rules for process movement

Study Aids

Key Formulas

- Total Cost = Computing Costs + Communication Costs
- Optimal scheduling condition: $\frac{r}{c} > \frac{N}{2}$
- Clustering costs: Computation = $\sum r_i$, Communication = $\sum c_{in} + \sum c_{out}$

Important Concepts

- Granularity: Computation-to-communication ratio
- Homogeneous vs Heterogeneous systems
- Static vs Dynamic scheduling
- Centralized vs Decentralized control
- Sender vs Receiver initiated load balancing

[Mnemonic] "GCD SL" - Granularity, Cost, Dynamism for Scheduling and Load balancing [Concept Map]

- Process Assignment → Where (Mapping)
- Scheduling → When (Timing)
- Load Balancing → How (Distribution)
- Static vs Dynamic approaches
- Centralized vs Decentralized control
- Homogeneous vs Heterogeneous systems