Lecture 37:

Parallel Programming Systems and Models

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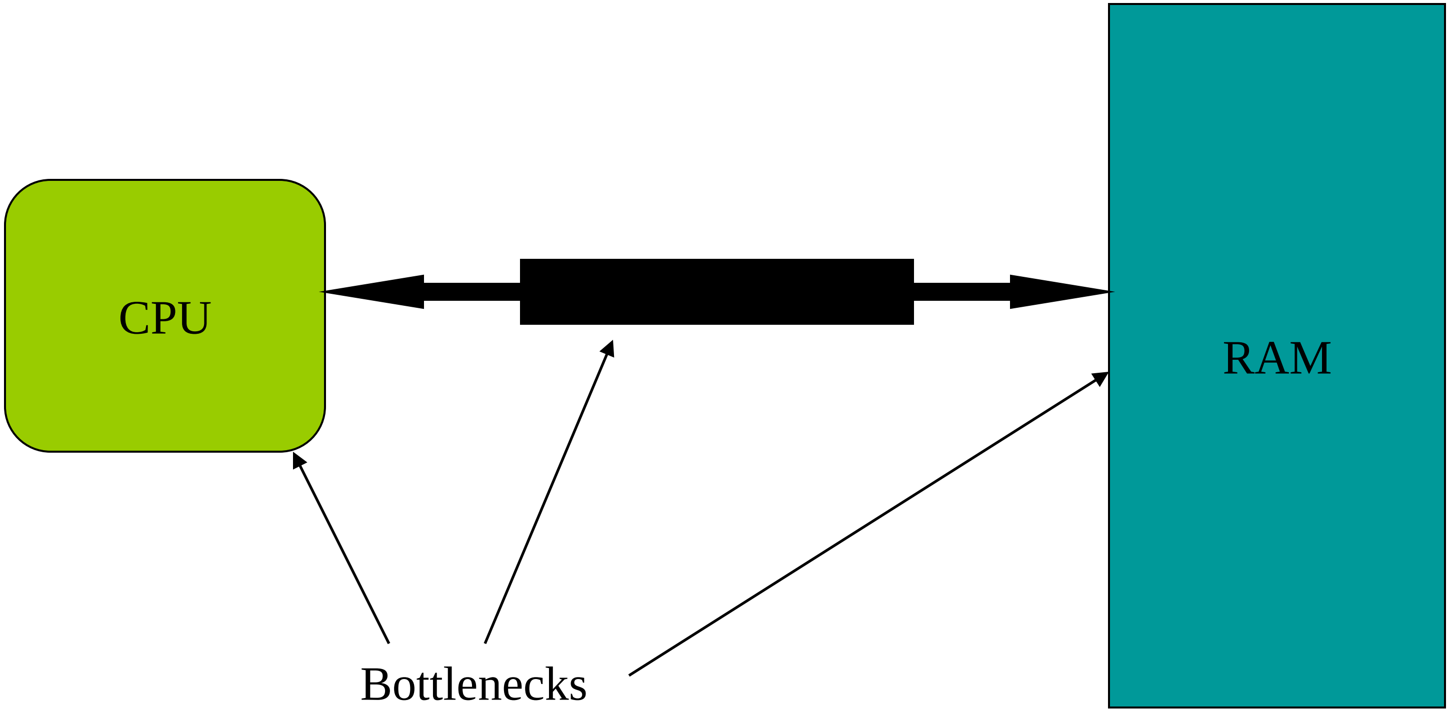
Parallel Architectures

- Standard sequential architecture

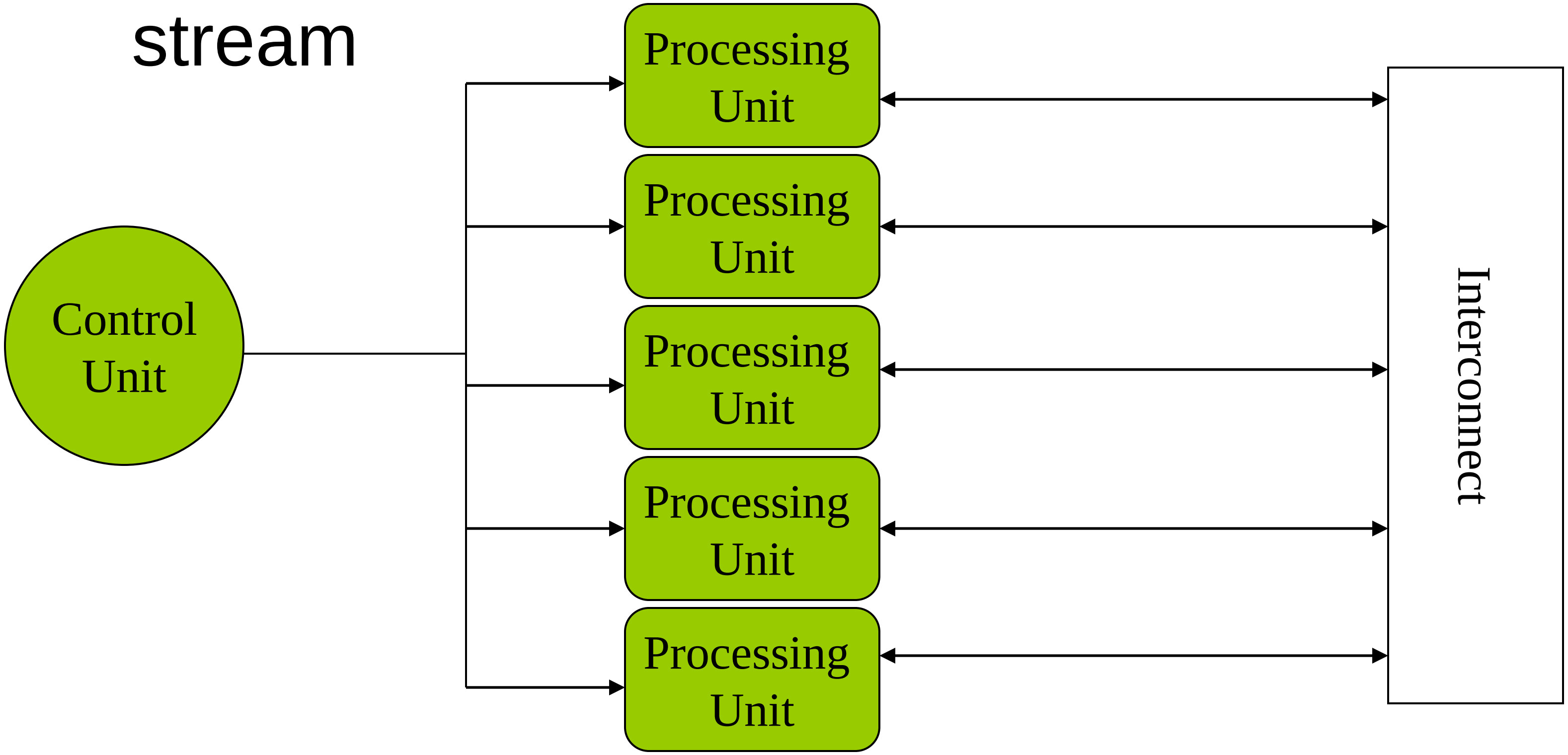


Parallel Architectures

- Use multiple
  - Datapaths
  - Memory units
  - Processing units

Parallel Architectures

- SIMD
  - Single instruction stream, multiple data stream

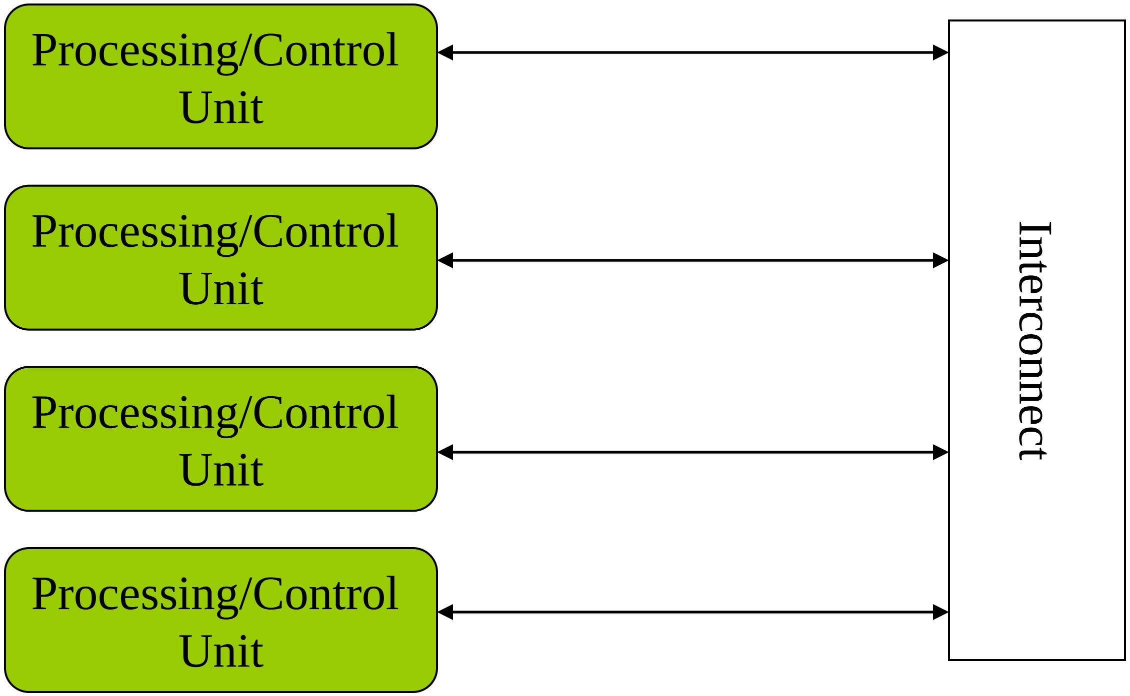


Parallel Architectures

- SIMD
  - Advantages
    - Performs vector/matrix operations well
      - EX: Intel's MMX chip
  - Disadvantages
    - Too dependent on type of computation
      - EX: Graphics
    - Performance/resource utilization suffers if computations aren't "embarrasingly parallel".

Parallel Architectures

- MIMD
  - Multiple instruction stream, multiple data stream



Parallel Architectures

- MIMD
  - Advantages
    - Can be built with off-the-shelf components
    - Better suited to irregular data access patterns
  - Disadvantages
    - Requires more hardware (!sharing control unit)
    - Store program/OS at each processor

- Ex: Typical commodity SMP machines we see today.

Parallel Architectures

- Task Communication
  - Shared address space
    - Use common memory to exchange data
    - Communication and replication are implicit
  - Message passing
    - Use send()/receive() primitives to exchange data
    - Communication and replication are explicit

Parallel Architectures

- Shared address space
  - Uniform memory access (UMA)
    - Access to a memory location is independent of which processing unit makes the request.
  - Non-uniform memory access (NUMA)
    - Access to a memory location depends on the location of the processing unit relative to the memory accessed.

Parallel Architectures

- Message passing
  - Each processing unit has its own private memory
  - Exchange of messages used to pass data
  - APIs
    - Message Passing Interface (MPI)
    - Parallel Virtual Machine (PVM)

Parallel Algorithms

- Algorithm
  - a sequence of finite instructions, often used for calculation and data processing.
- Parallel Algorithm
  - An algorithm that which can be executed a piece at a time on many different processing devices, and then put back together again at the end to get the correct result

Parallel Algorithms

- Challenges
  - Identifying work that can be done concurrently.
  - Mapping work to processing units.
  - Distributing the work
  - Managing access to shared data
  - Synchronizing various stages of execution.

Parallel Algorithms

- Models
  - A way to structure a parallel algorithm by selecting decomposition and mapping techniques in a manner to minimize interactions.

Parallel Algorithms

- Models
  - Data-parallel
  - Task graph
  - Work pool
  - Master-slave
  - Pipeline
  - Hybrid

Parallel Algorithms

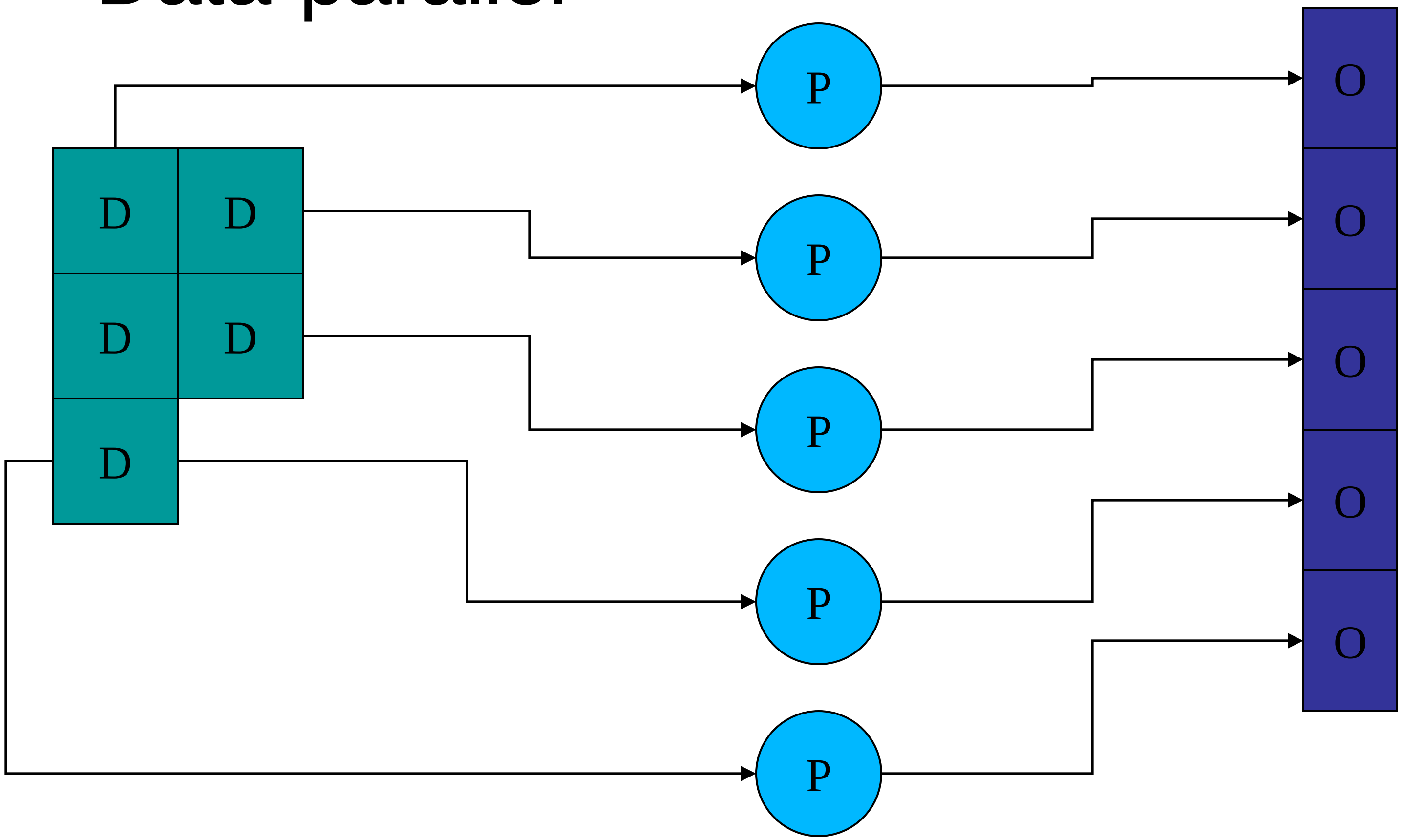
- Data-parallel
  - Mapping of Work
    - Static
    - Tasks -> Processes
  - Mapping of Data
    - Independent data items assigned to processes (Data Parallelism)

Parallel Algorithms

- Data-parallel
  - Computation
    - Tasks process data, synchronize to get new data or exchange results, continue until all data processed
  - Load Balancing
    - Uniform partitioning of data
  - Synchronization
    - Minimal or barrier needed at end of a phase
  - Examples
    - Ray Tracing

Parallel Algorithms

- Data-parallel



Parallel Algorithms

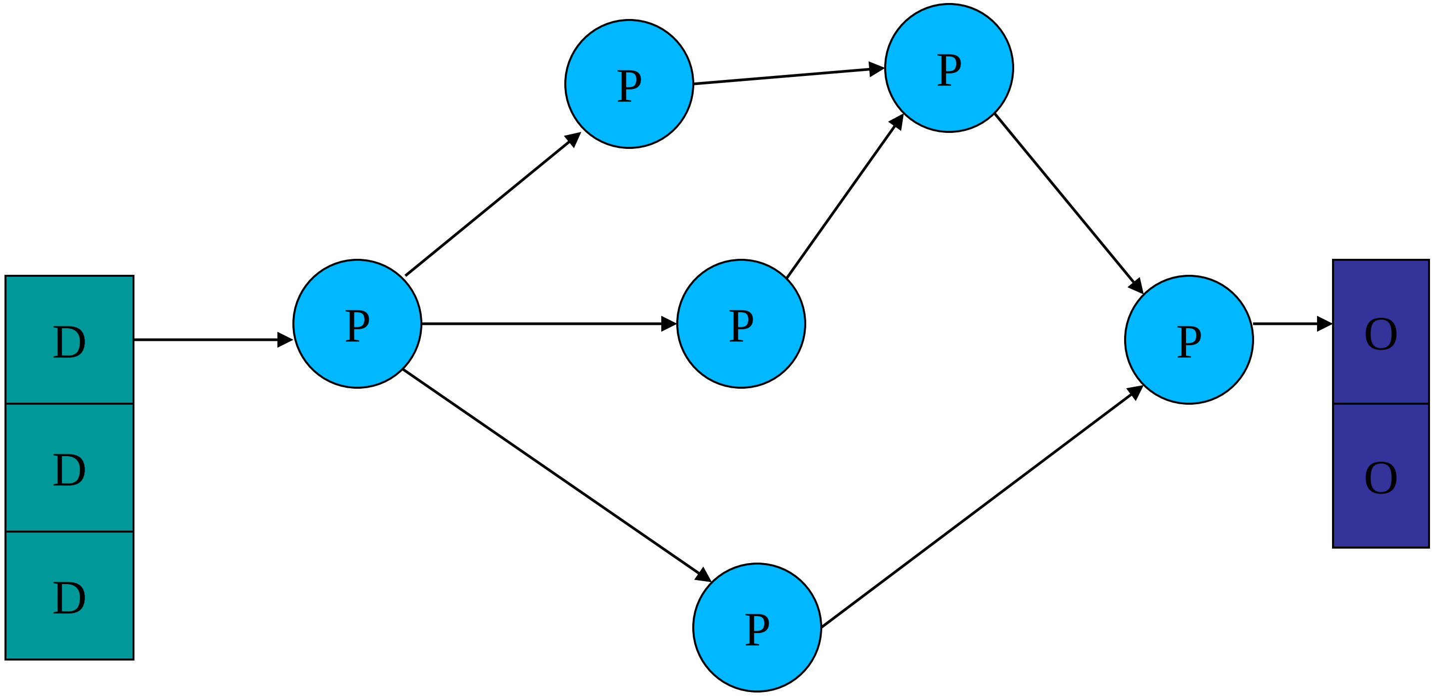
- Task graph
  - Mapping of Work
    - Static
    - Tasks are mapped to nodes in a data dependency task dependency graph (Task parallelism)
  - Mapping of Data
    - Data moves through graph (Source to Sink)

Parallel Algorithms

- Task graph
  - Computation
    - Each node processes input from previous node(s) and send output to next node(s) in the graph
  - Load Balancing
    - Assign more processes to a given task
    - Eliminate graph bottlenecks
  - Synchronization
    - Node data exchange
  - Examples
    - Parallel Quicksort, Divide and Conquer approaches
    - Scientific Applications that can be expressed in workflows (e.g. DAGs)

Parallel Algorithms

- Task graph



Parallel Algorithms

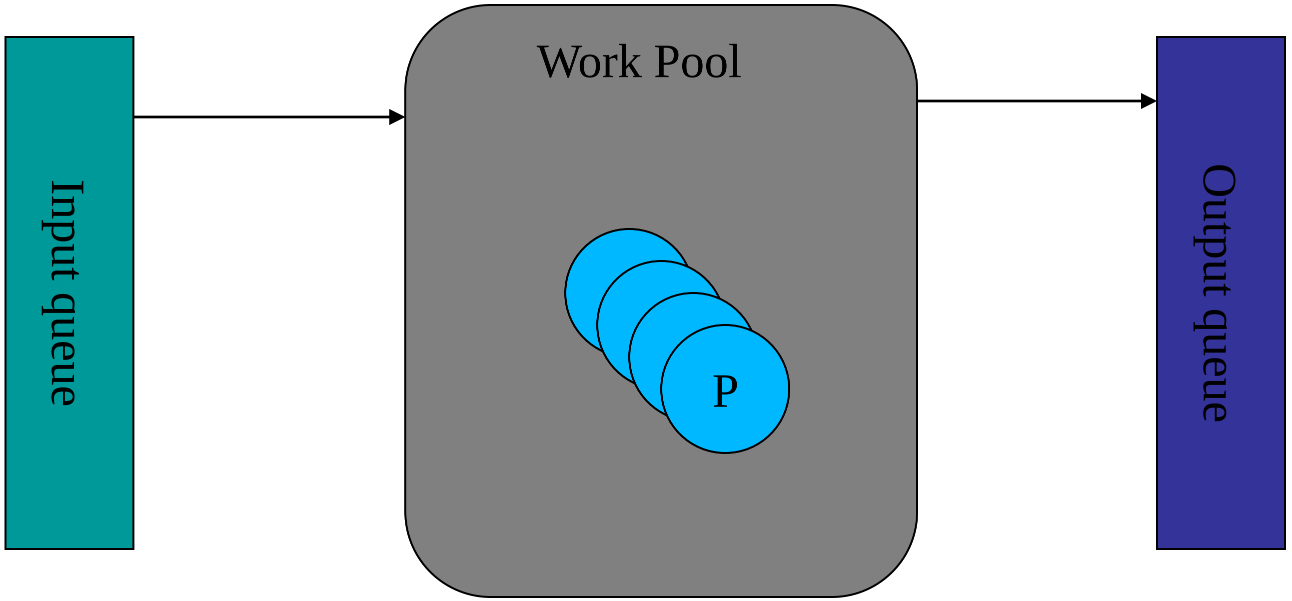
- Work pool
  - Mapping of Work/Data
    - No desired pre-mapping
    - Any task performed by any process
    - Pull-model oriented
  - Computation
    - Processes work as data becomes available (or requests arrive)

Parallel Algorithms

- Work pool
  - Load Balancing
    - Dynamic mapping of tasks to processes
  - Synchronization
    - Adding/removing work from input queue
  - Examples
    - Web Server
    - Bag-of-tasks

Parallel Algorithms

- Work pool



Parallel Algorithms

- Master-slave
  - Modification to Worker Pool Model
    - One or more Master processes generate and assign work to worker processes\
    - Push-model oriented
  - Load Balancing
    - A Master process can better distribute load to worker processes

Parallel Algorithms

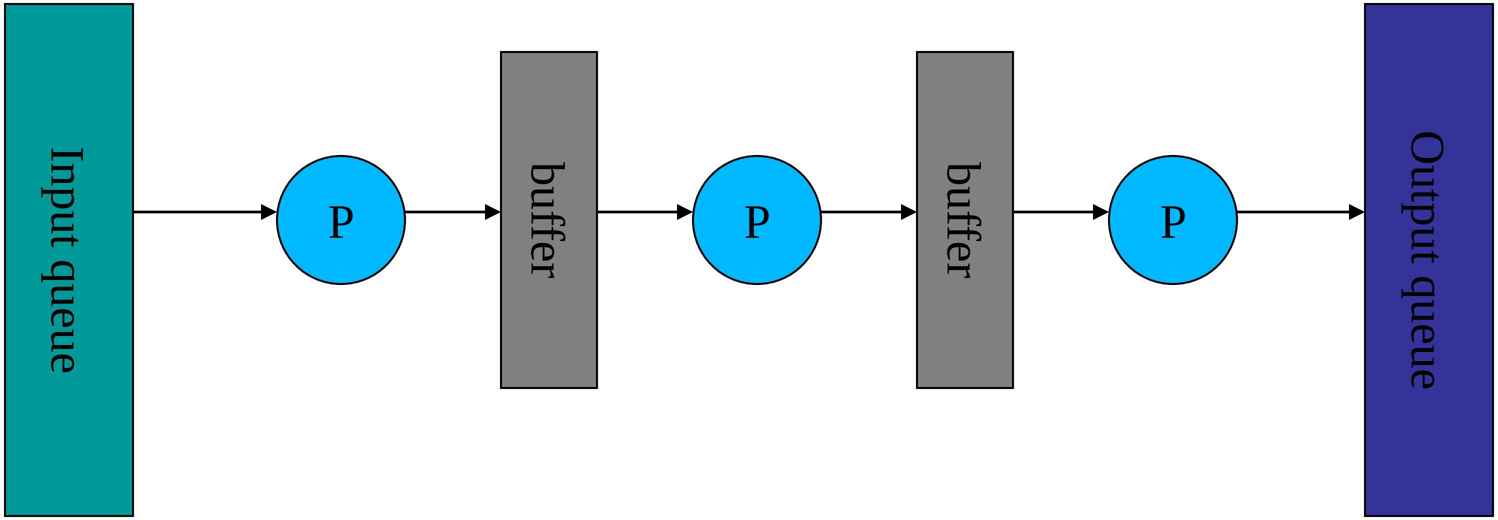
- Pipeline
  - Mapping of work
    - Processes are assigned tasks that correspond to stages in the pipeline
    - Static
  - Mapping of Data
    - Data processed in FIFO order
      - Stream parallelism

Parallel Algorithms

- Pipeline
  - Computation
    - Data is passed through a succession of processes, each of which will perform some task on it
  - Load Balancing
    - Insure all stages of the pipeline are balanced (contain the same amount of work)
  - Synchronization
    - Producer/Consumer buffers between stages
  - Ex: Processor pipeline, graphics pipeline

Parallel Algorithms

- Pipeline



Questions

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