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- Static load-balancing: the algorithm decides *a priori* how to divide the workload.
- Dynamic load-balancing: the algorithm collects statistics while it runs and uses that information to rebalance the workload across the processes as it runs.

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- Recursive bisection: Recursively divide a problem into sub-problems of equal computational effort.
- Heuristic techniques: For example, a genetic algorithm to determine a good static load balanced workload.

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Manages a queue of tasks, known as the workpool.

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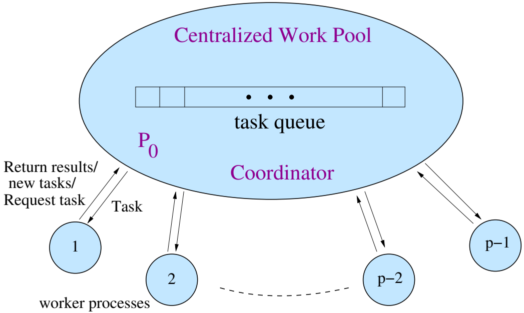
Two styles of dynamic load balancing:

- Centralized Workpool: The workpool is kept at a coordinator process, which hands out tasks and collects newly generated tasks from worker processes.
- Distributed Workpool: The workpool is distributed across the worker processes. Tasks are exchanged between arbitrary processes. Requires a more complex *termination detection* technique to know when the program has finished.

Centralized Workpool



- The workpool holds a collection of tasks to be performed. Processes are supplied with tasks when they finish previously assigned task and request for another task. This leads to load balancing. Processes can generate new tasks to be added to the workpool as well.

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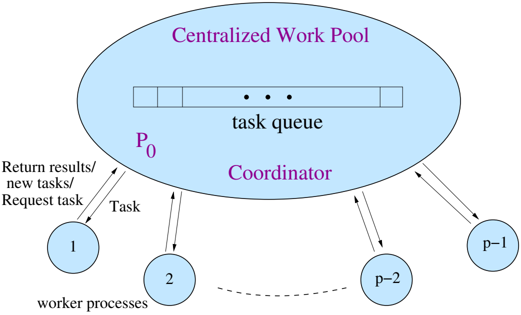

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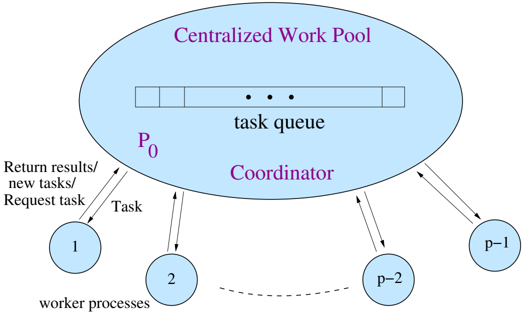

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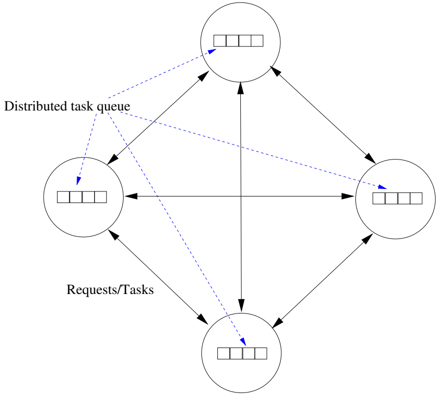
- **Termination**: The workpool program is terminated when
  - the task queue is empty, and
  - each worker process has made a request for another task without any new tasks being generated.

Distributed Workpool



- The task of queues is distributed across the processes.
- Any process can request any other process for a task or send it a task.
- Suitable when the memory required to store the tasks is larger than can fit on one system.

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- *Round robin*.
- *Random polling*.
- *Structured*: The processes can be arranged in a logical ring or a tree.

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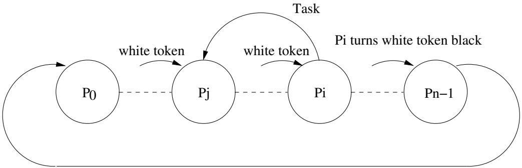
- Tree-based termination algorithm. A tree order is imposed on the processes based on who sends a message for the first time to a process. At termination the tree is traversed bottom-up to the root.
- Dual-pass token ring algorithm. A separate phase that passes a token to determine if the distributed algorithm has finished. The algorithm specifically detects if any messages were in transit.

Dual-pass Token Ring Termination



- Process 0 becomes white when terminated and passes a "white" token to process 1.

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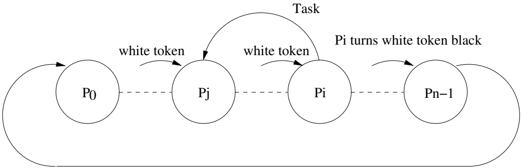

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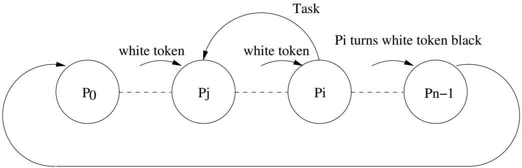

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- If process 0 receives a “white” token, termination conditions have been met. If it receives a “‘black” token, it starts a new ring with another “white token.”

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- Graph can be represented in two different ways:
  - **Adjacency matrix**: A two dimensional array $w[0 \dots n-1][0 \dots n-1]$ holds the weight of the edges.
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- Sequential shortest paths algorithms
  - *Dijstkra*'s shortest paths algorithm: Uses a priority queue to grow the shortest paths tree one edge at a time: has limited opportunities for parallelism.
  - *Moore*'s shortest path algorithm: Works by finding new shorter paths all over the graph. Allows for more parallelism but can do extra work by exploring a given vertex multiple times.

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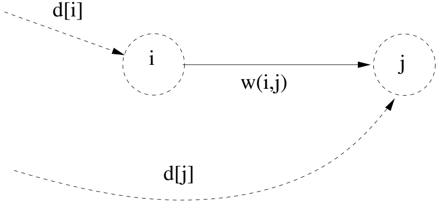

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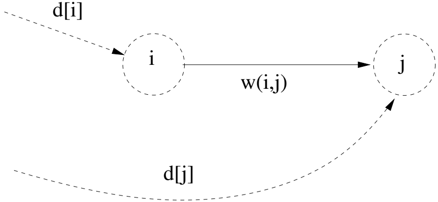

- Repeat until the vertex queue is empty.

Shortest Paths using Centralized Workpool

- *Task* (for Shortest paths): One vertex to be explored.
- *Coordinator process (process 0)*: Holds the workpool, which consists of the queue of vertices to be explored. This queue shrinks and grows dynamically.

Centralized Workpool Pseudo-Code

```
centralized_shortest_paths(s, w, n, p, id)
// id: current process id, total p processes, numbered 0,...,p−1
// s - source vertex, w[0..n-1][0..n-1] - weight matrix, dist[0..n-1] shortest distance
// Q - queue of vertices to explore, initially empty
coordinator ← 0
bcast(w, &n, coordinator);
// the coordinator part
if (id = coordinator)
    numWorkers ← 0
    enqueue(Q, s)
    do  recv(P_any, &worker, ANY_TAG, &tag)
        if (tag = NEW_TASK_TAG)
            recv(&j, &newdist, P_any, &worker, NEW_TASK_TAG)
            dist[j] ← min(dist[j], newdist[j])
            enqueue(Q, j)
        else if tag = INIT_TAG or tag = REQUEST_TAG
            if (tag = REQUEST_TAG)
                numWorkers ← numWorkers - 1
            if (queueNotEmpty(Q))
                v ← dequeue(Q)
                send(&v, P_worker, TASK_TAG)
                send(dist, &n, P_worker, TASK_TAG)
                numWorkers ← numWorkers + 1
    while (numWorkers > 0)
    for i ← 1 to p-1
    do  send(&dummy, P_i, TERMINATE_TAG)
```

Centralized Workpool Pseudo-Code (contd.)

```
else
    //the worker part
    send(&id, P_coordinator, INIT_TAG)
    recv(&v, P_coordinator, ANY_TAG, &tag)
    while tag ≠ TERMINATE_TAG)
        recv(dist, &n, P_coordinator, TASK_TAG)
        for j ← 0 to n-1
        do  if w[v][j] ≠ ∞
                newdist_j ← dist[v] + w[v][j]
                if newdist_j < dist[j]
                    dist[j] ← newdist_j
                    send(&id, P_coordinator, NEW_TASK_TAG)
                    send(&j, &newdist_j, P_coordinator, NEW_TASK_TAG)
        send(&id, P_coordinator, REQUEST_TAG)
        recv(&v, P_coordinator, ANY_TAG, &tag)
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- Updating local copy of distance array would eliminate many tasks from being created in the first place. This would give further improvement.
- Use a priority queue instead of a FIFO queue for workpool. This should give some more improvement for large enough graphs.

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- Process i keeps track of the ith entry of the distance array.
- Process i stores the adjacency matrix row or adjacency list for vertex i.

If a process receives a message containing a distance, it checks with its stored value and if it is smaller, it updates distances to its neighbors and send messages to the corresponding processes

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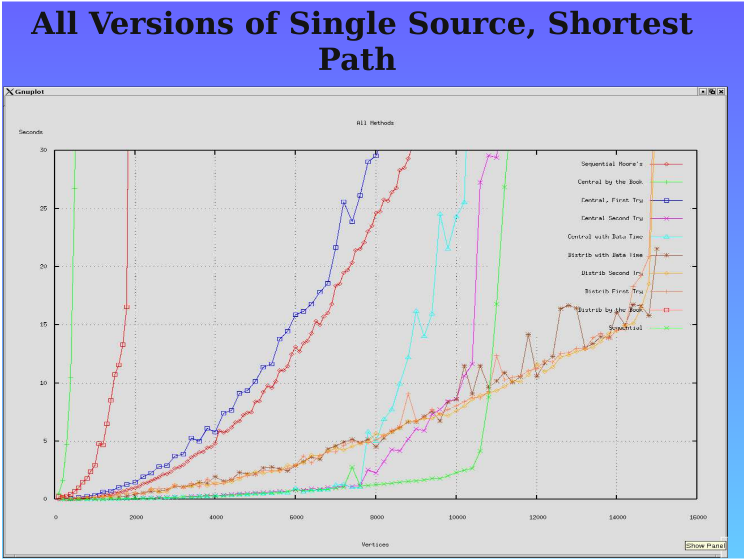
In actual implementation, the distributed workpool solution (with the optimizations) was able to scale much more than the centralized solution.

Comparison of Various Implementations



Further Reading

- *Pencil Beam Redefinition Algorithm*: A dynamic load balancing scheme that is adaptive in nature. The statistics are collected centrally but the data is rebalanced in a distributed manner! This is based on an actual medical application code.
- *Parallel Toolkit Library*: Masters project by Kirsten Allison. This library gives a centralized and distributed workpool design pattern that any application programmer can use without having to implement the same complex patterns again and again.

Notes on both are on the class website under lecture notes.