Patterns for Parallel Programming

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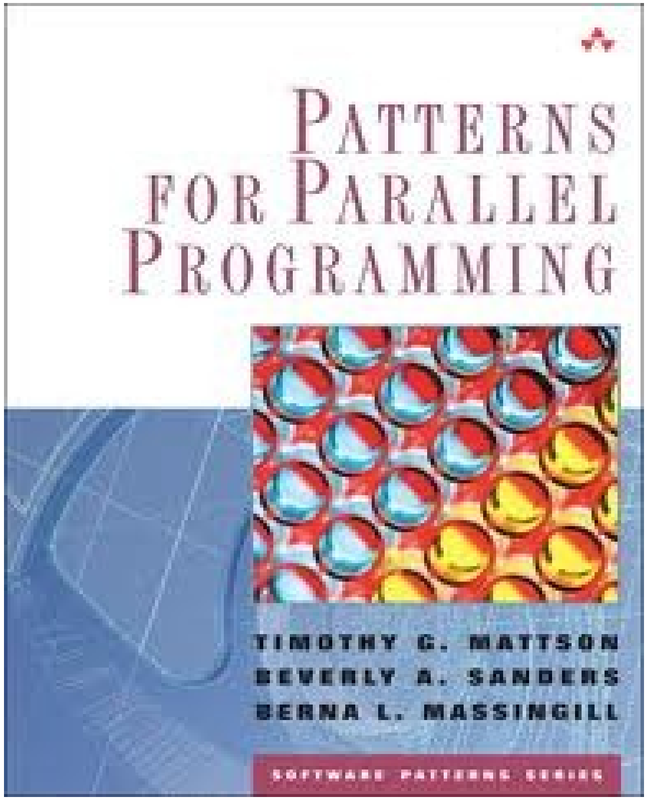

Timothy Mattson , Beverly Sanders , Berna Massingill,
Patterns for parallel programming, Addison-Wesley Professional, 2004
ISBN-13: 978-0321228116

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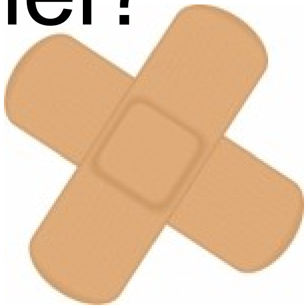
Sticking Plaster Pitfall

"Could you just tweak my serial code to make it run in parallel?"



Why Bother With This Book?

- Recipe based
  - Recipes guide our thinking
  - Help us not to forget
- Introduces recurrent themes and terminology
  - e.g. (memory) latency, “loop parallelism”
- Emphasises ***design***
  - Amdahl's law highlights the pitfalls of looking for sticking-plaster speed-ups in serial programs – design for concurrency

Familiar Mantras - ..only more so

Flexibility

Environments will be more heterogeneous.

Efficiency

We're going parallel for a speed-up, right?

But more pitfalls (latency, thread overheads etc.)

Simplicity

Parallel codes will be more complicated.

All the more reason to strive for maintainable, understandable programs.

Four Design Spaces

Finding Concurrency

↕

Algorithm Structure

↕

Supporting Structures

↕

Implementation Mechanisms

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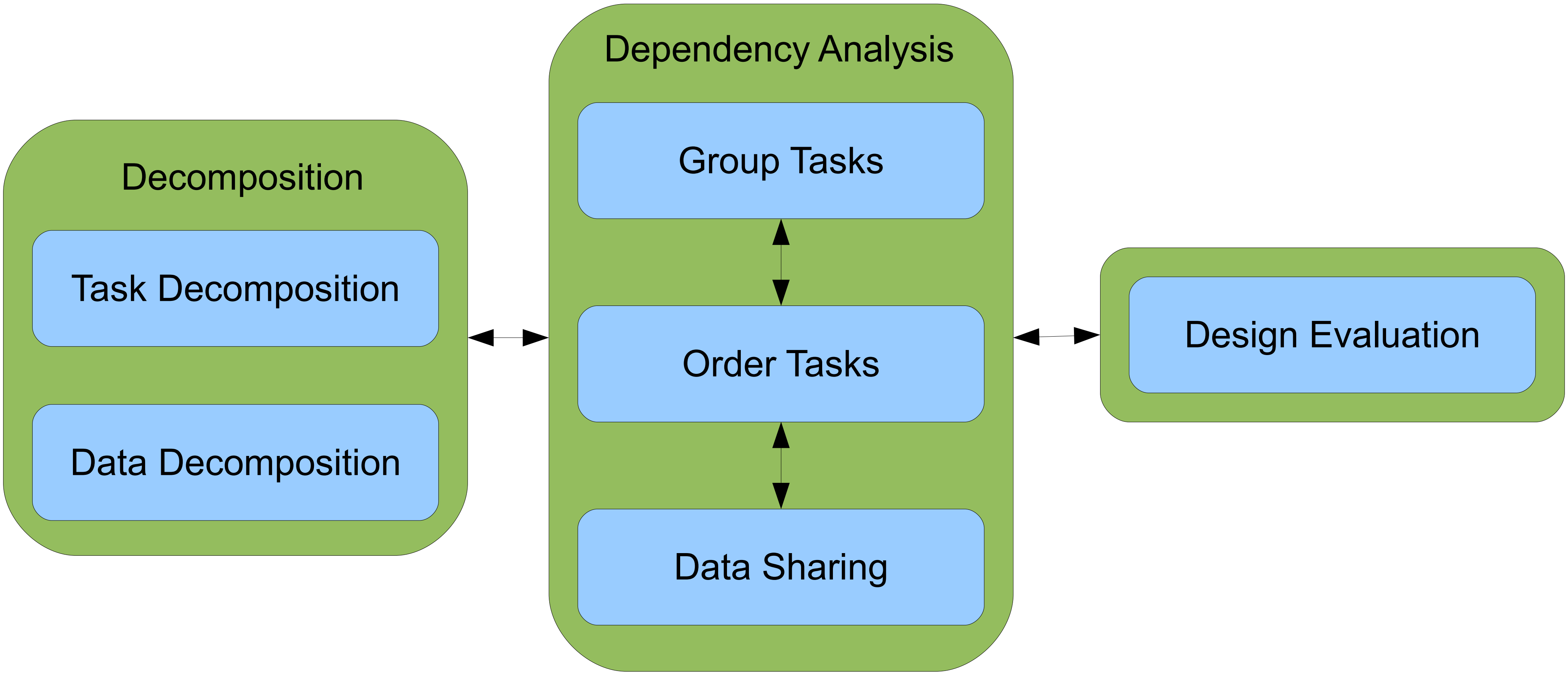
Finding Concurrency

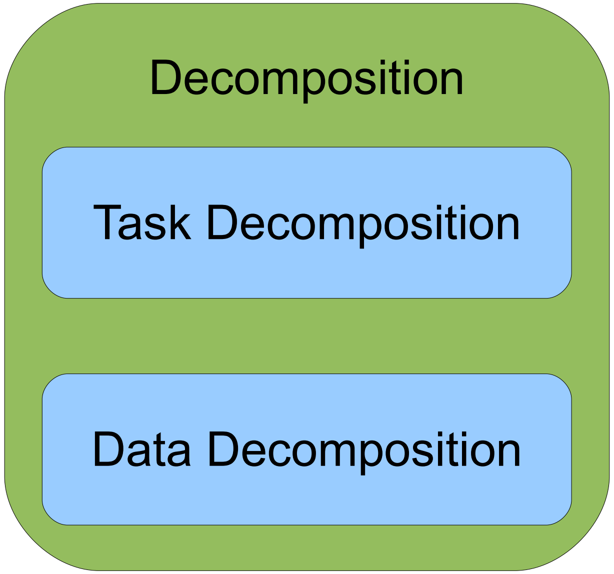


Examples

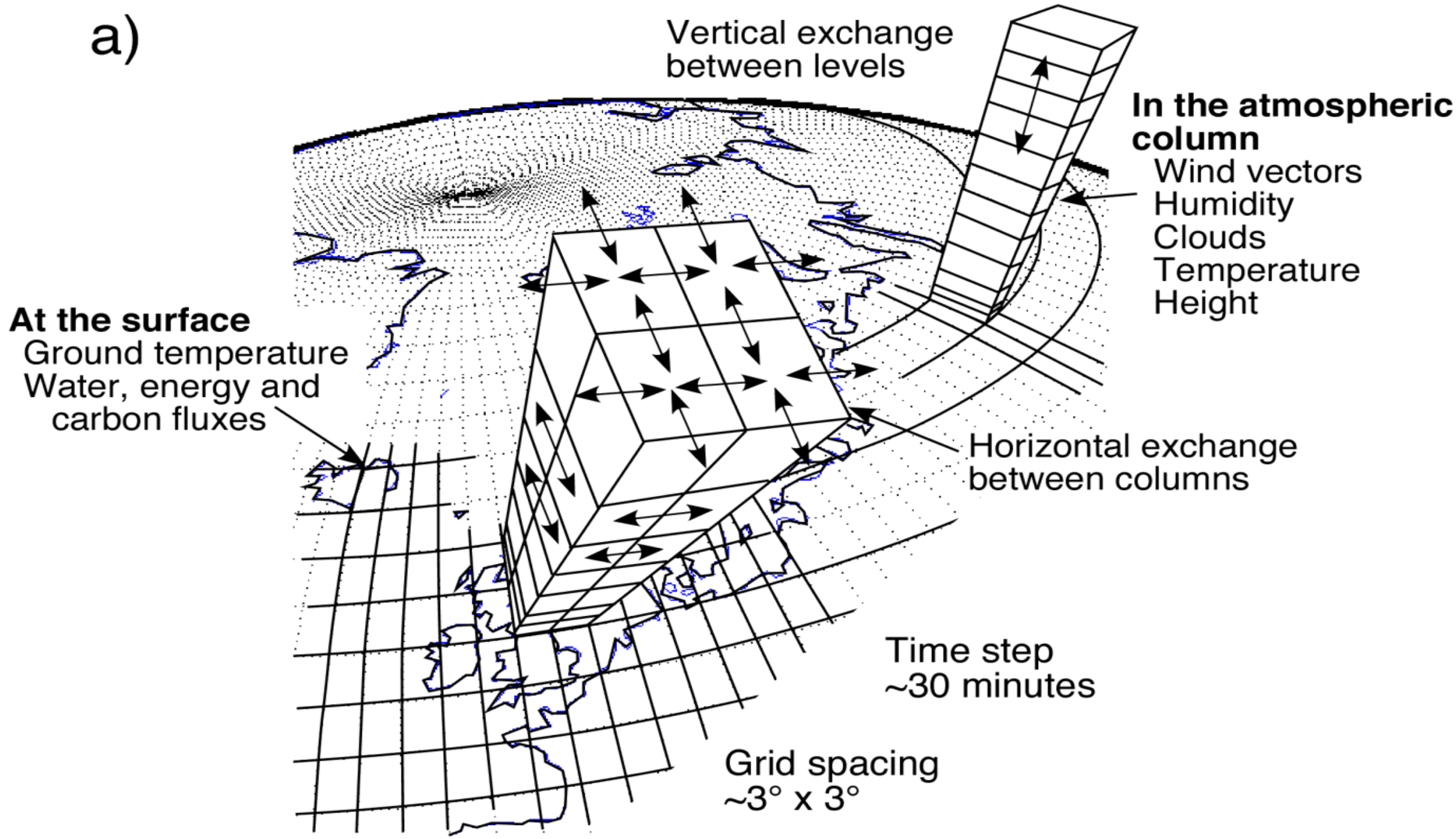
- HPC: A Climate Model
- Embedded Systems: A Speech Recogniser
- The Cloud: Document Search

Highlights the fact that parallel programming is emerging everywhere..

Task vs. Data Decomposition



Data Decomposition (trad. HPC): A Climate Model



Data Parallel over grid cells

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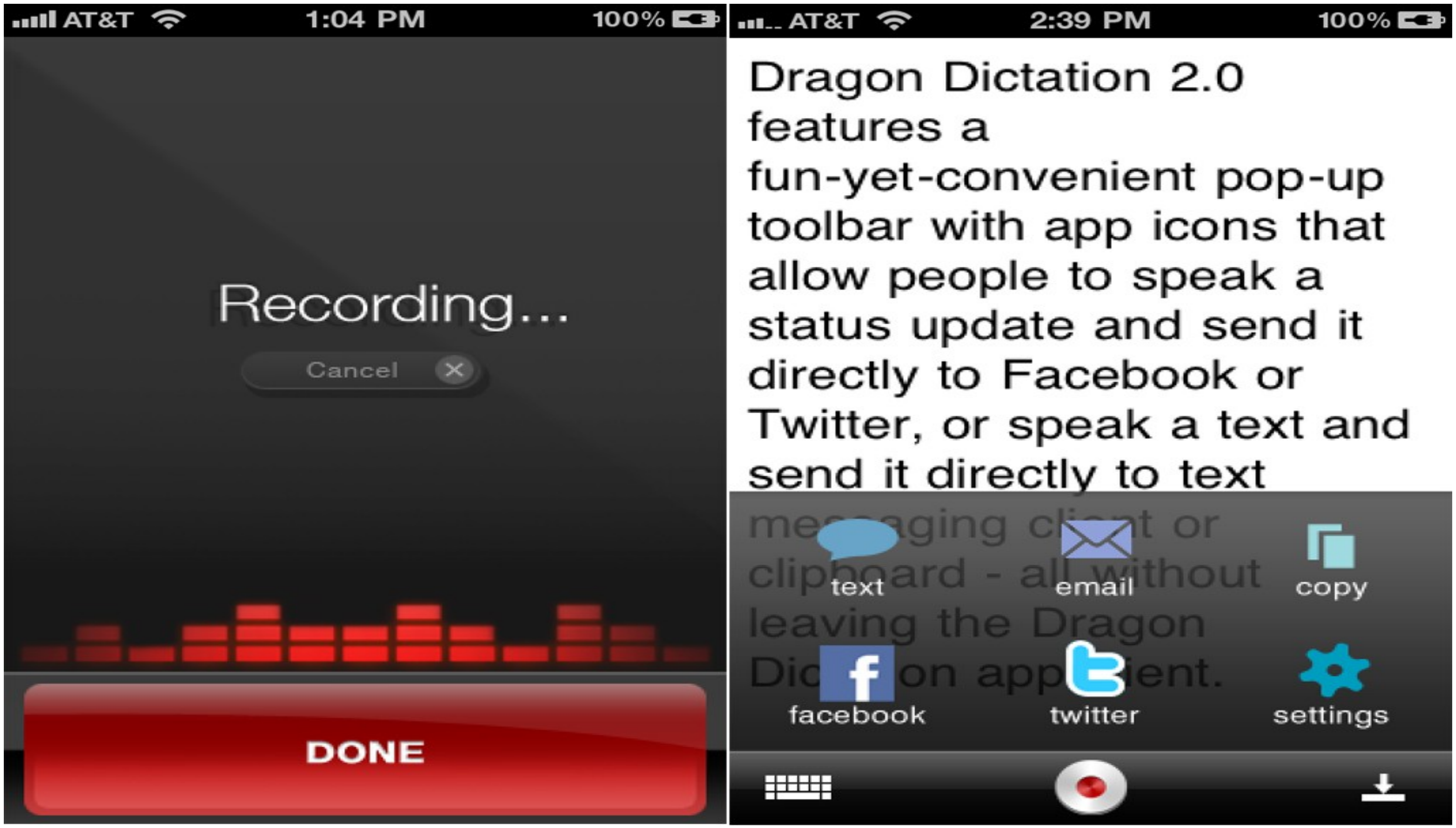
Task Decomposition (Embedded): A Speech Recogniser



Acoustic Analysis: concurrency in stages and components
Pattern Matching: search over many possible word matches

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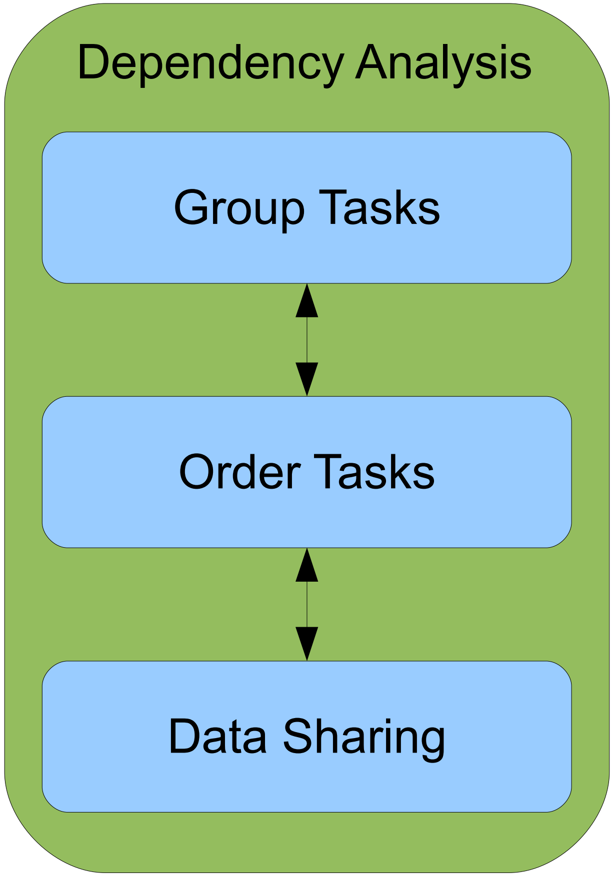
Finding Relationships between Concurrent Tasks



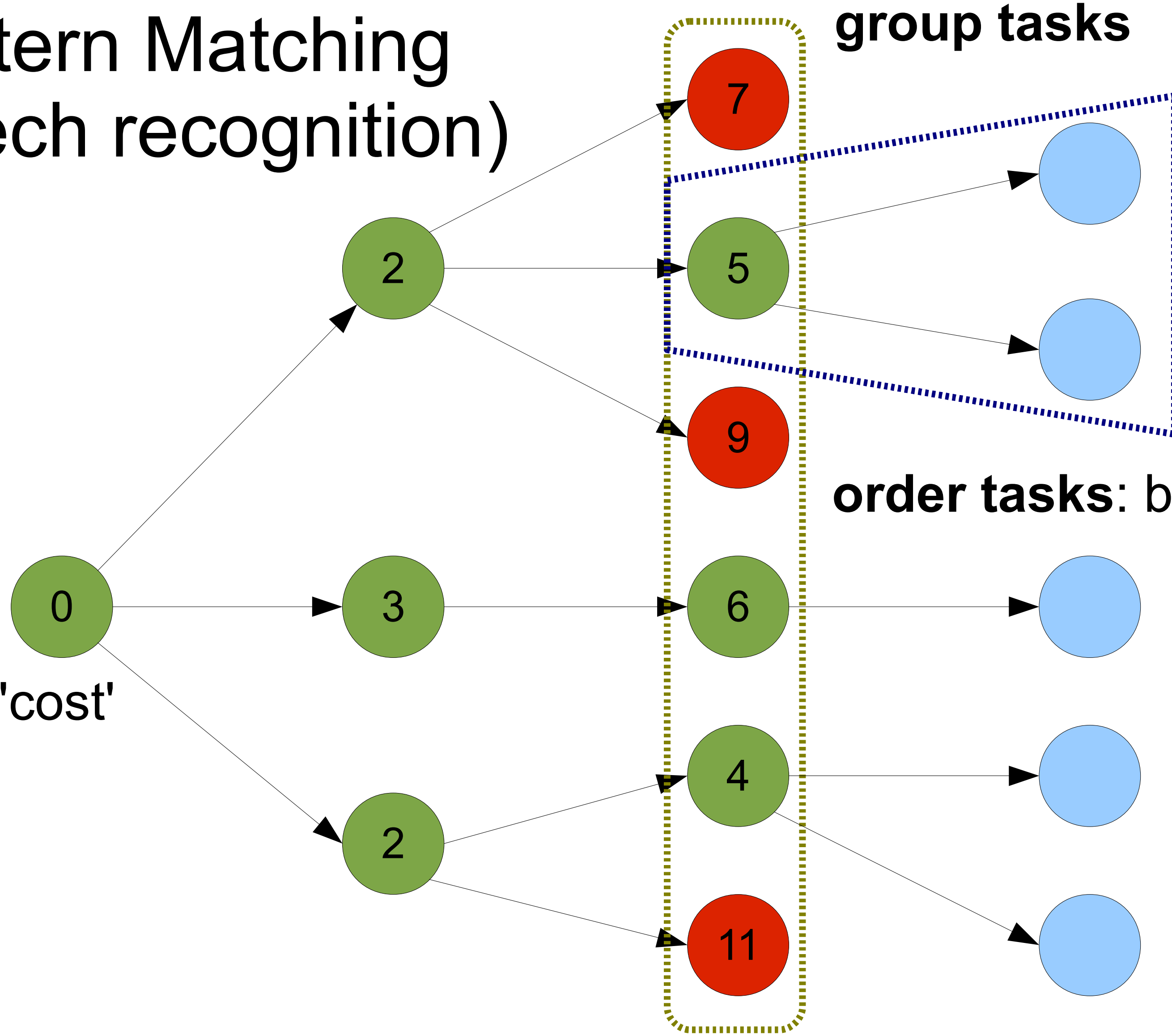
Dependency Analysis

Pattern Matching (speech recognition)

group tasks

data sharing:
- queue of paths
- legal branches
- acoustic i/p

order tasks: branch..& bound



match 'cost'

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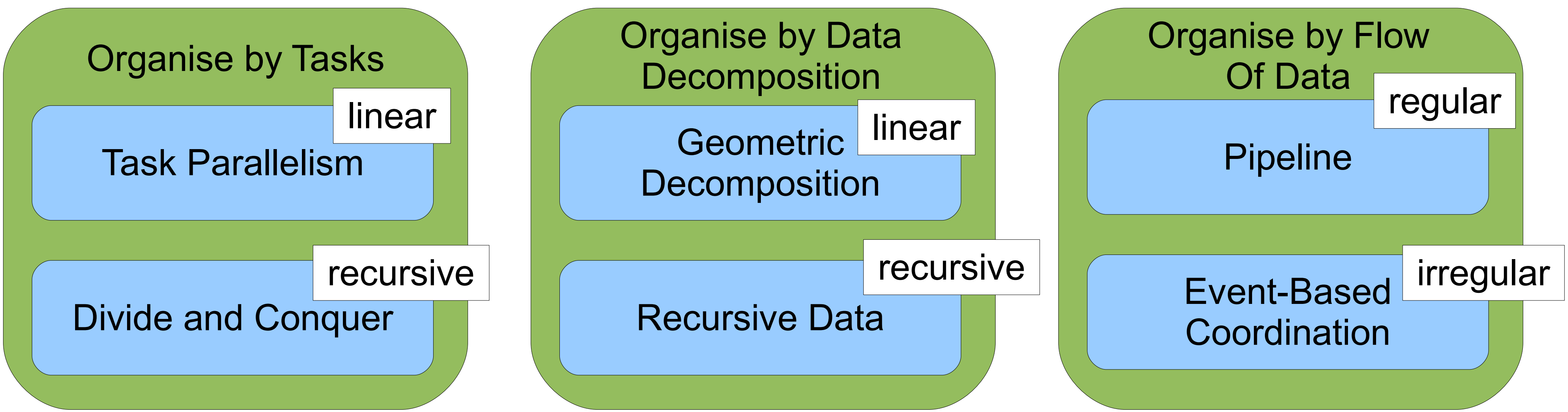
Algorithm Structure



Organise by Tasks - Some Considerations

- No dependencies between tasks
  - massively parallel (vs. embarrassingly serial!)
- Dependencies between tasks
  - Temporal (e.g. speech: real-time constraints)
  - Separable – 'reductions' (we'll see later)
- Cost of setting up task vs. amount of work done
  - See thresholds to switch to serial work (we'll see this in e.g. quicksort)

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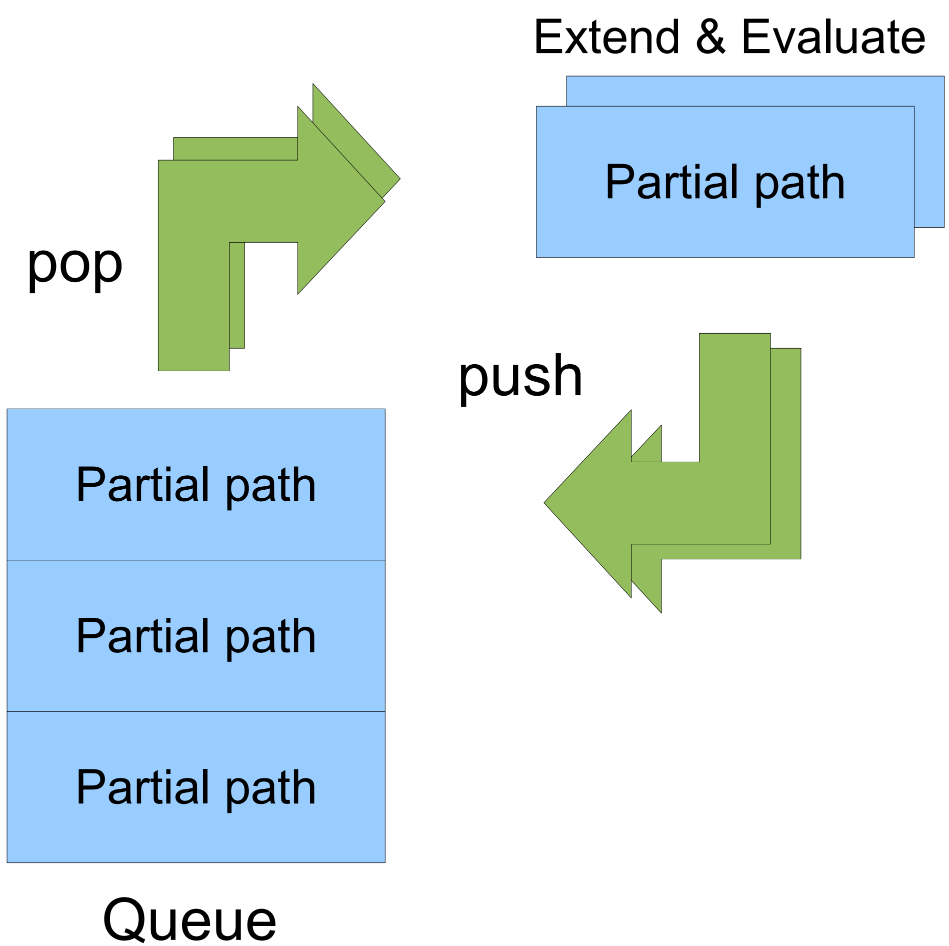
Organise by Tasks - Task Parallelism



<u>Shared data:</u>
Queue of partial paths
Bounding criterion

Branch & bound implemented with a shared queue

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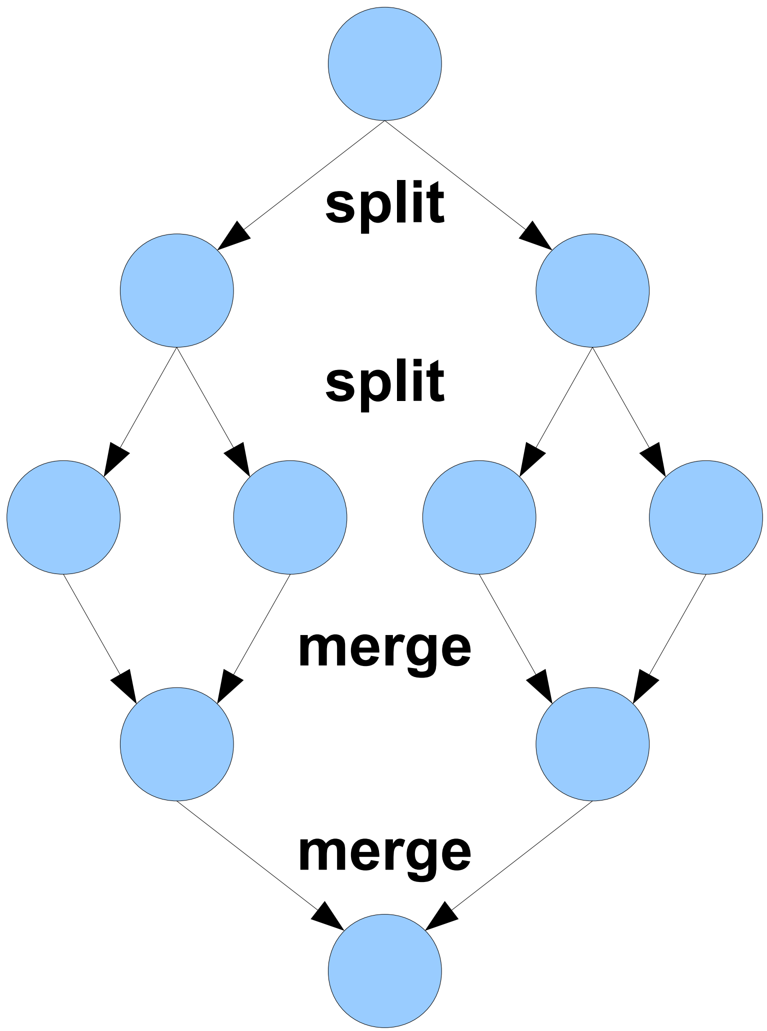
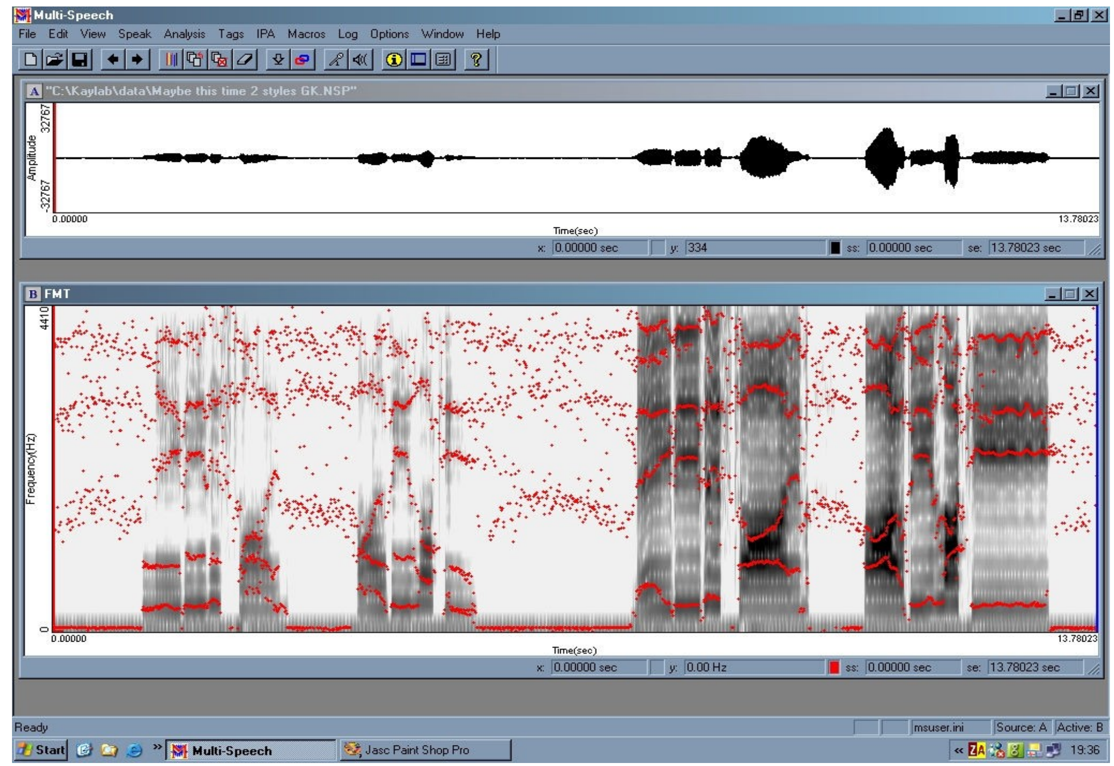
Organise by Tasks - Divide and Conquer





e.g. FFT for speech recognition
Sorting algorithms

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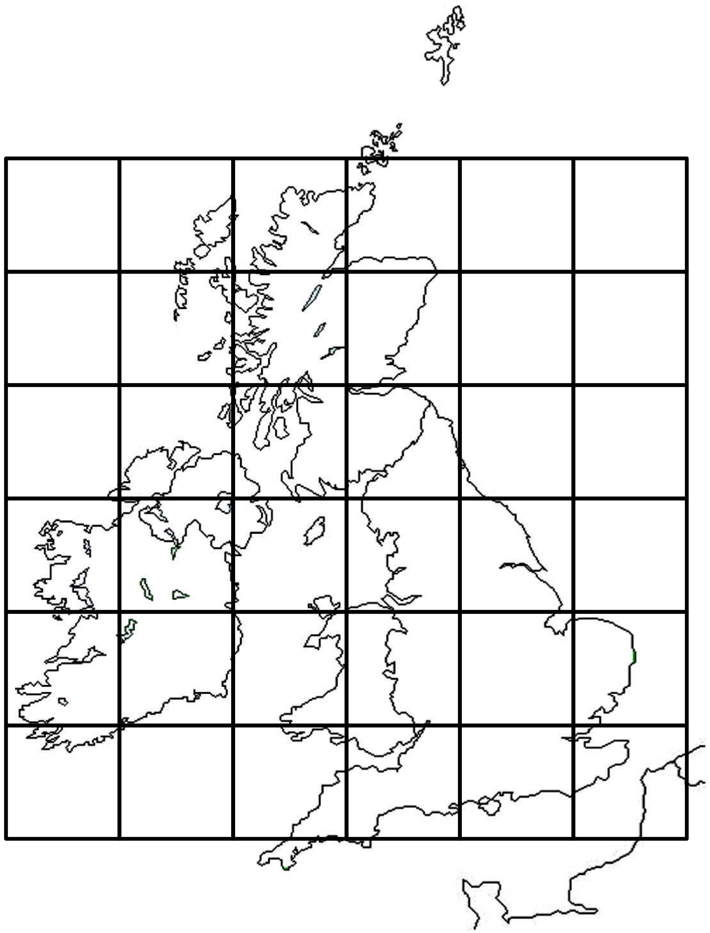
Organise by Data Decomposition - Geometric Decomposition



Grid Cells

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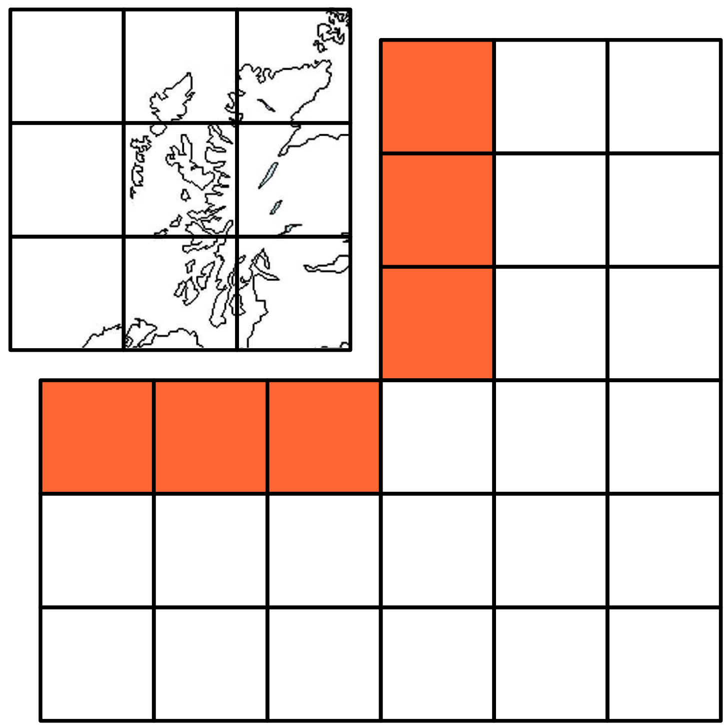
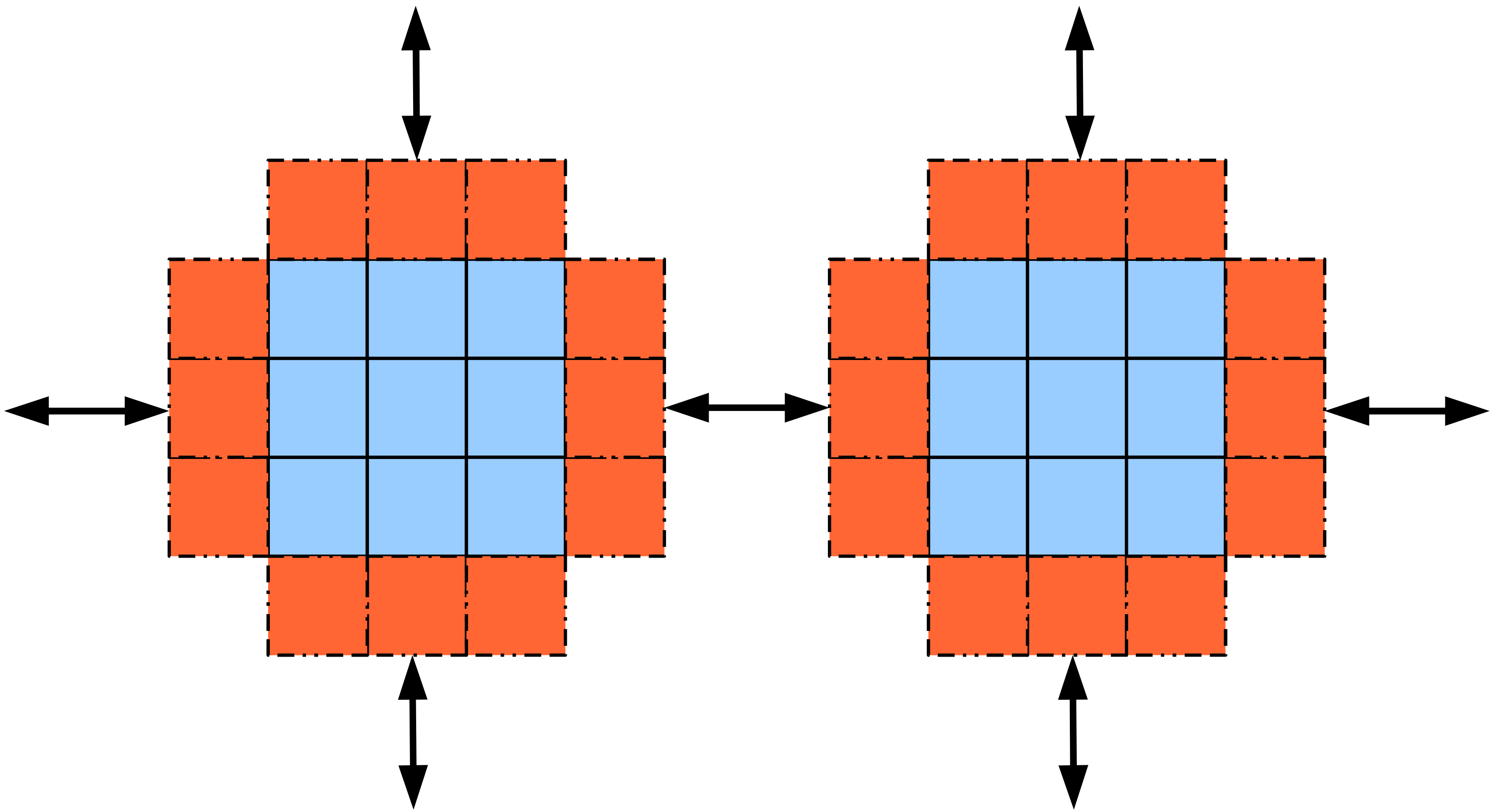
Organise by Data Decomposition - Geometric Decomposition

cells assigned to single processor



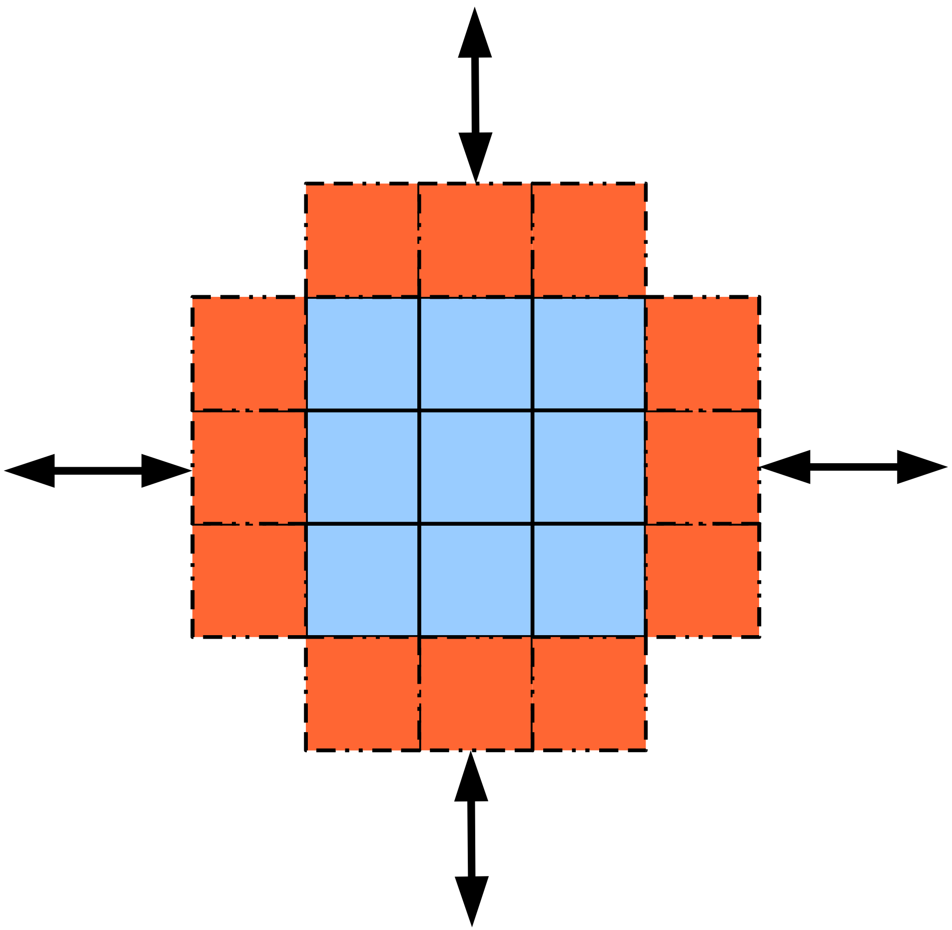
Exchange local data with neighbours

Organise by Data Decomposition - Geometric Decomposition



Halo exchange

Organise by Data Decomposition - Geometric Decomposition



<u>Benefits of halo exchange:</u>

1. **Can overlap communication & computation**
2. **Compute scales with volume but communication scales with surface area**

Q. What's wrong with the number of grid cells here?

Bonus Q. Any issues with the grid on a globe? Any solutions?

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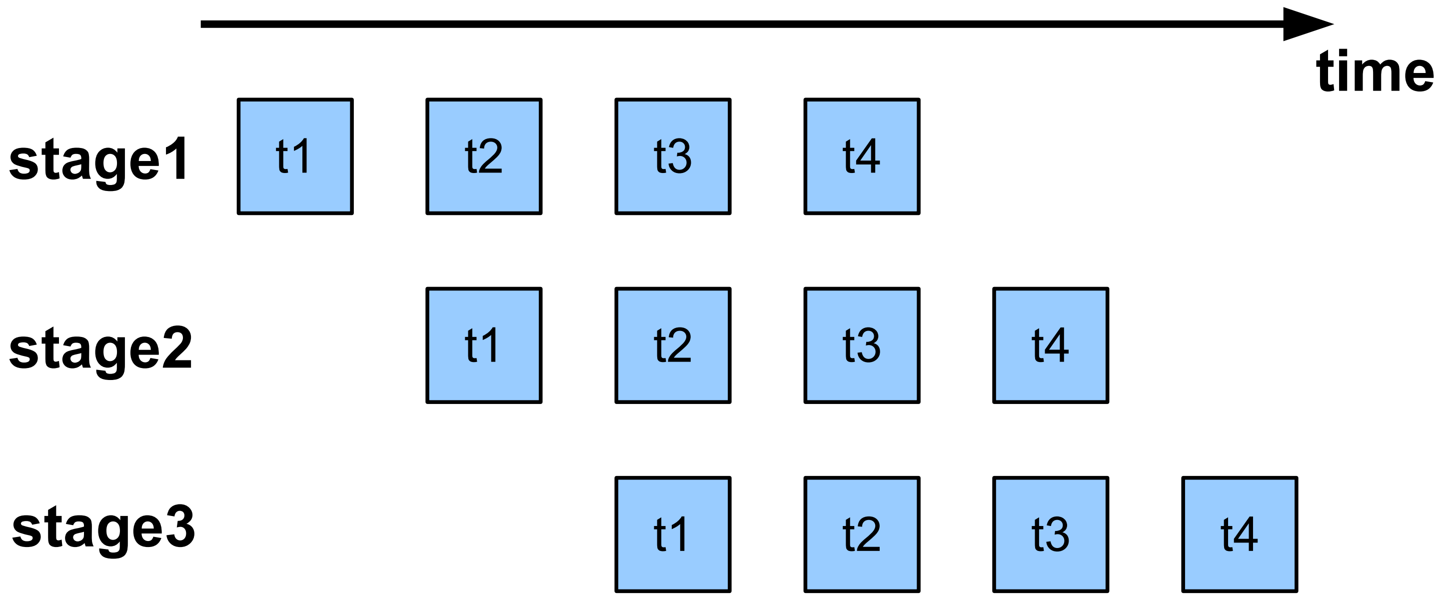
Pipeline

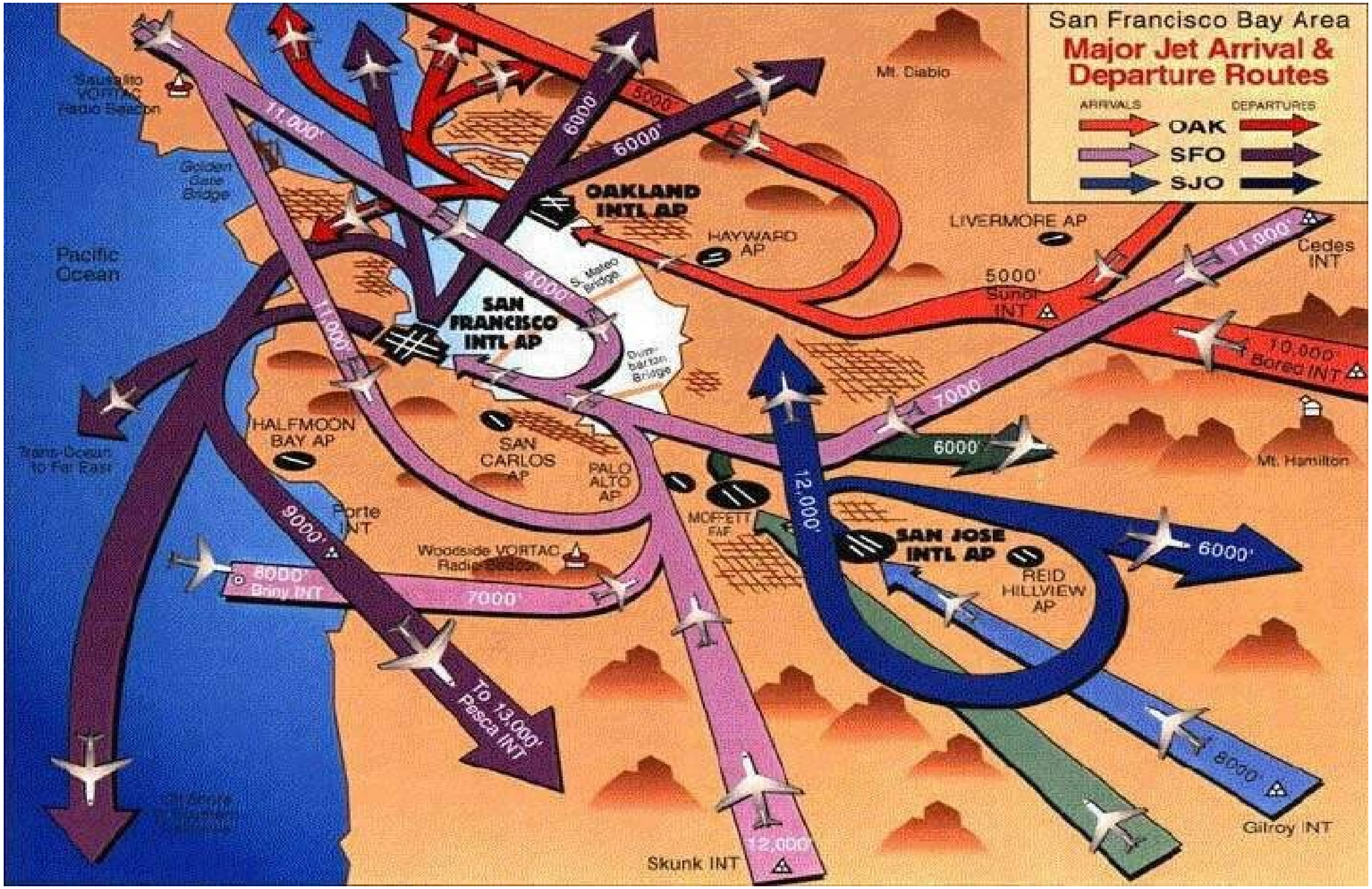
Pipeline



<u>Speech recognition:</u>

1. Discrete Fourier Transform (DFT)
2. manipulation e.g. log
3. Inverse DFT
4. Truncate 'Cepstrum' ..

Event-Based Coordination



Irregular events, ordering constraints (queues can be handy)

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Supporting Structures

Program Structures

- SPMD
- Master/Worker
- Loop Parallelism
- Fork/Join

Program Structures

- Shared Data
- Shared Queue
- Distributed Array

Useful **idioms** rather than unique implementations

Single Program Multiple Data

rank = 0

```
if(rank == 0) {
printf("MASTER\n");
}
else {
printf("OTHER\n");
}
```

rank = 1

```
if(rank == 0) {
printf("MASTER\n");
}
else {
printf("OTHER\n");
}
```

- Only one program to manage
- Conditionals based on thread or process IDs
- Load balance predictable (implicit in branching)
- Plenty of examples and practice when we look at MPI

Master/Worker

Use when load balance is not predictable..

..& work cannot be distributed using loops

- PEs may have different capabilities
- A bag of independent tasks is ideal
- Workers take from bag, process, then take another

Load is **automatically** balanced in this way

Master/Worker (Cloud): MapReduce

<u>Big Data:</u>
Google Processed 20PB/day in 2008 using MapReduce
Also used by Yahoo, FaceBook, eBay etc.

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Loop Parallelism

Use if computational expense is concentrated in loops (common in scientific code)

1. Profile code to find 'hot-spots'
2. Eliminate dependencies between iterations (e.g. private copies & reductions)
3. Parallelise loops (easy in OpenMP)
4. Tune the performance, e.g. via scheduling

We'll get plenty of practice with OpenMP

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Fork/Join

Use if the number of concurrent tasks varies, e.g. if tasks are created recursively

- Beware: overhead of creating a new UEs (Uinits of Execution, e.g. thread or process)
  - Direct vs. indirect mappings from tasks to Ues
- Sorting algos are an examples

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Shared Data

- Try to avoid, as can limit scalability
- Use a concurrency-controlled (e.g. 'thread-safe') data type:
  - One-at-a-time: critical region/'mutex'
  - Look for non-interfering operations e.g. readers vs. writers
  - If pushed, finer grained critical regions, but this will increase complexity & hence the chance of a bug
- 'Shared Queue' is an instance of 'Shared Data'

Distributed Arrays

In a nutshell: partition data and distribute so that data is close to computation.

- Why? Memory access (esp. over a network) is slow relative to computation.
- Simple concept but the devil is in the details
- Some terminology:
  - 1D block, 2D block and block cyclic distribution

Libraries: e.g. ScaLAPACK

Recap of Key Points

Design..

- for massively parallel systems
- because if not today they will be tomorrow
- and in all areas of computing

Design Patterns..

- provide useful – recurring - solutions
- & structure to the process

Implementation Mechanisms

OpenMP & Pthreads

MPI

OpenCL