A language approach to accelerating dynamic programming problems on the GPU

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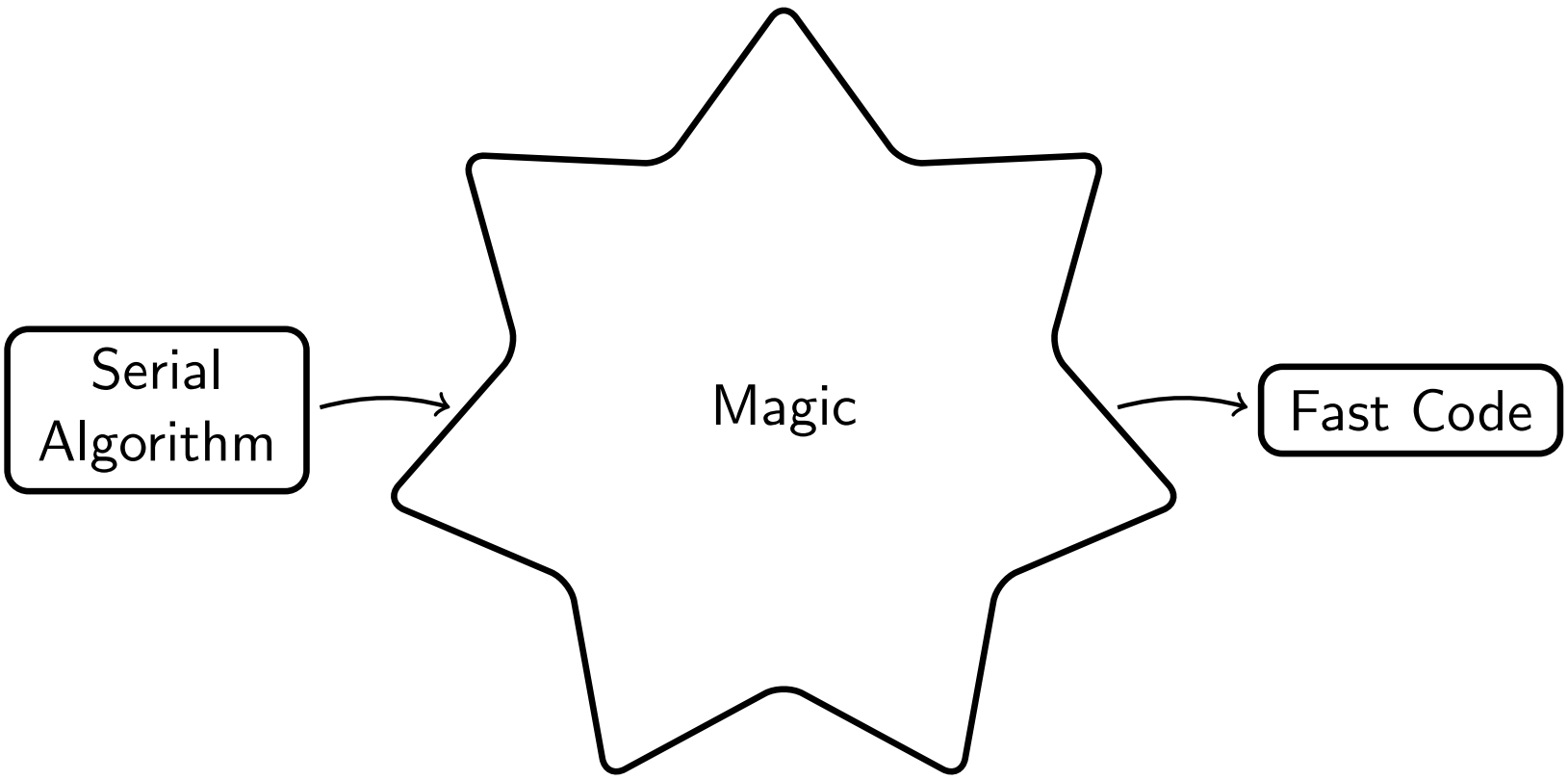
Mapping problems is (can be?) hard

What the user wants:



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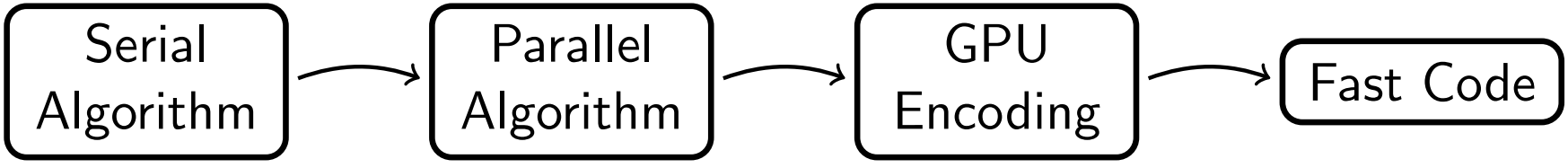
What the user gets:

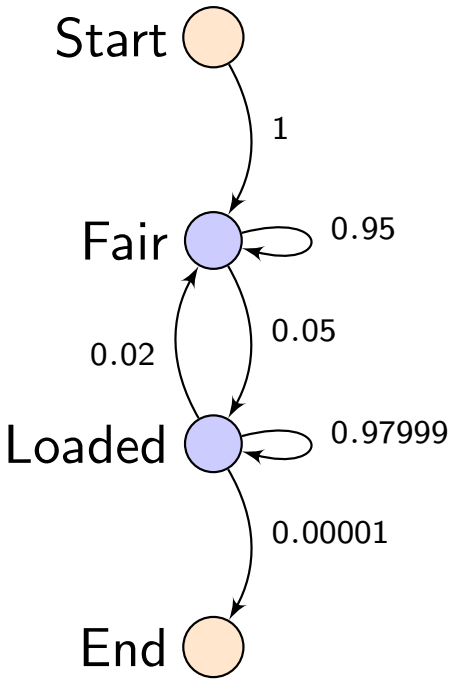


Difficult Questions?

- Which parts of the program will we parallelise?
- Can we appeal to data-parallelism? Problem-level parallelism?
- Size of the block? Size of the grid?
- Shared memory? Cached memory? Registers?

Can we answer these questions in a meaningful way if we focus on domains?

Bioinformatics as a domain



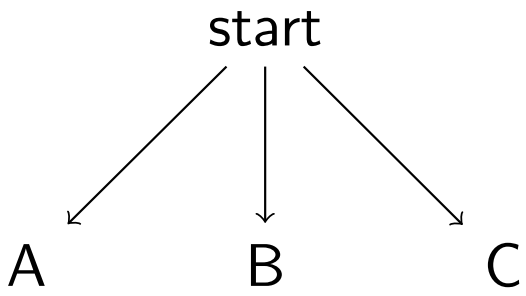
HMMingbird

- A Hidden Markov Model compiler
- Targets NVIDIA GPUs, using C for CUDA.
- Describes a fixed set of algorithms using templates.

Roadmap

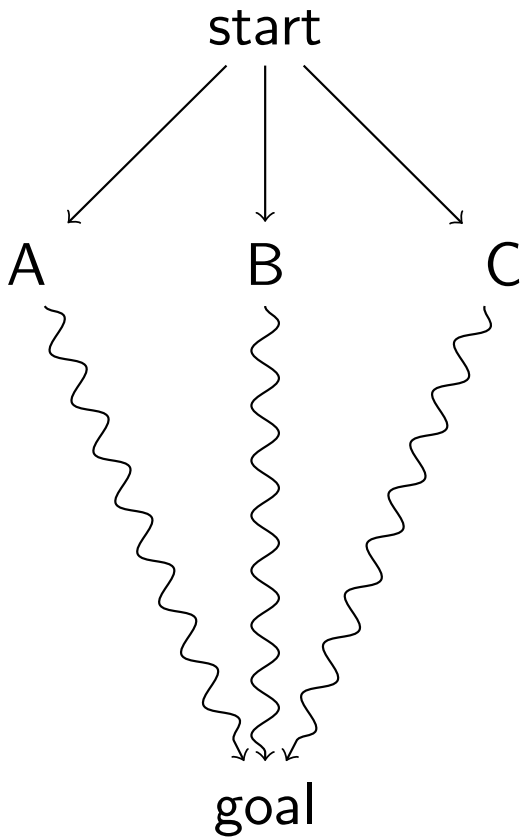
- Data Definition Layer - HMMingbird
- Algorithm Definition Layer - Functional language for optimisation problems

Optimisation Problems



Choices

Optimisation Problems



Choices

Optimal Substructure

Edit distance

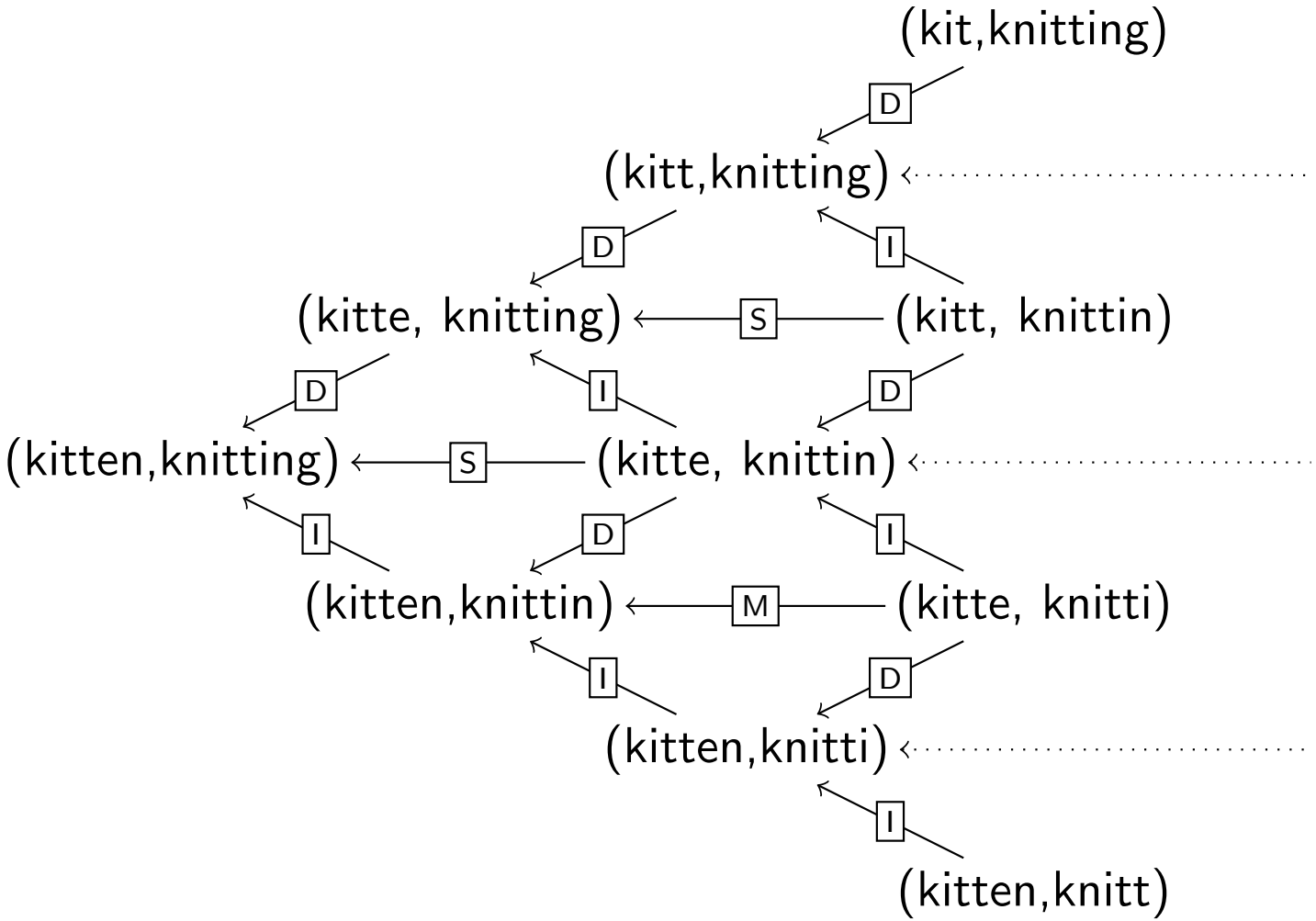
Minimum operations required to transform one string to another.
e.g

$$\text{kitten} \implies \text{kitten}\mathbf{g}\ (\text{I})$$

$$\text{kitteng} \implies \text{kitt}\mathbf{i}\text{ng}\ (\text{S})$$

$$\text{kitting} \implies \text{k}\mathbf{n}\text{itting}\ (\text{I})$$

Graph problem



Recursion

$$f(x,y) = \begin{cases} x & \text{if } y = 0 \\ y & \text{if } x = 0 \\ f(x-1,y-1) & \text{if } s[x] = t[y] \\ min(f(x-1,y), & \\ \quad f(x,y-1), & \text{otherwise} \\ \quad f(x-1,y-1)) + 1 & \end{cases}$$

Recursion in language

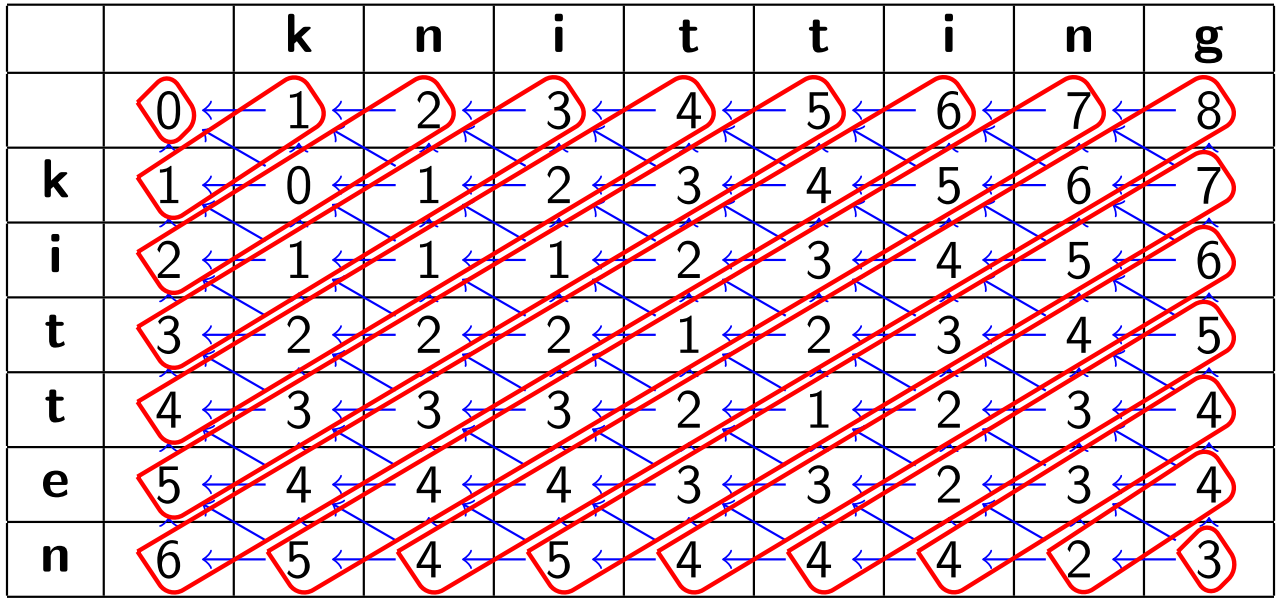
```
f(String s[x],String t[y]) = if x = 0 then y
          else if y = 0 then x
          else if s[x - 1] = t[y - 1] then f(x - 1,y - 1)
          else min(f(x - 1, y),f(x, y - 1), f(x - 1, y- 1)) + 1

f("kitten", "knitting")
```

Partitions

		k	**n**	**i**	**t**	**t**	**i**	**n**	**g**
	0	1	2	3	4	5	6	7	8
k	1	0	1	2	3	4	5	6	7
i	2	1	1	1	2	3	4	5	6
t	3	2	2	2	1	2	3	4	5
t	4	3	3	3	2	1	2	3	4
e	5	4	4	4	3	3	2	3	4
n	6	5	4	5	4	4	4	2	3

Partitions


k n i t t i n g
0 1 2 3 4 5 6 7 8
k 1 0 1 2 3 4 5 6 7
i 2 1 1 1 2 3 4 5 6
t 3 2 2 2 1 2 3 4 5
t 4 3 3 3 2 1 2 3 4
e 5 4 4 4 3 3 2 3 4
n 6 5 4 5 4 4 4 2 3

Partition function

Describe each partition based on the parameters e.g

$$P_f(x, y) = x + y$$

Proving suitability of a partition function

Consider each recursive call in turn using descent functions.

$$f(d_x(x,y), d_y(x,y))$$

e.g

$$f(\ x-1\ ,\ \ y-1\ )$$

Verify the recursive equation satisfies the partition function:

$$\forall_{x,y} P_f(x,y) > P_f(d_x(x,y), d_y(x,y))$$

e.g

$$\forall_{x,y} x + y > (x-1) + (y-1)$$

More analysis

Termination

Partition base case is when $P_f(x, y) = 0$:

The base case of the recursion needs to satisfy this.

Out of bounds check

We must also check the recursion never jumps out of bounds.

GPU Mapping

- Data-parallel/Problem-parallel
- Block size, grid size
- Sliding window optimisations

Questions solved?

Have we answered these?

- Which parts of the program will we parallelise?
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Further work

Tie work into higher-level domains for Bioinformatics
(e.g Hidden Markov Models)
Permit more sophisticated recursions