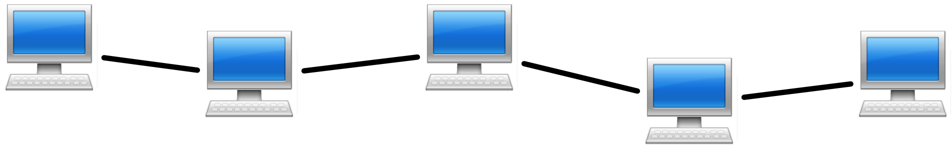
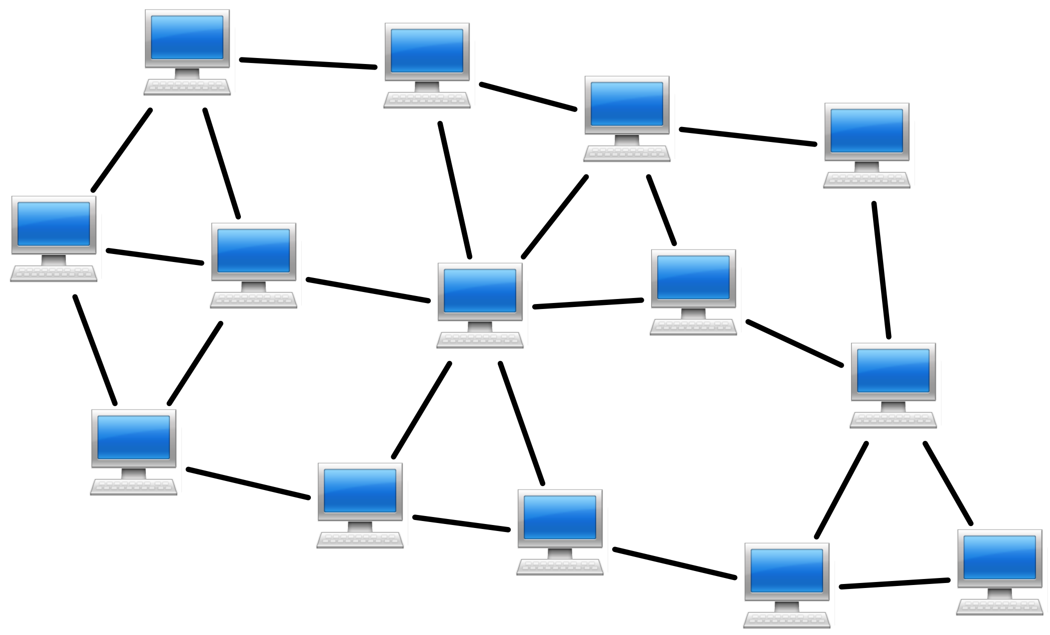
- **Weeks 1–2: informal introduction**
    - network = path 
- **Week 3: graph theory**
- **Weeks 4–7: models of computing**
    - what can be computed (efficiently)?
- **Weeks 8–11: lower bounds**
    - what cannot be computed (efficiently)?
- **Week 12: recap**

Week 12

– Conclusions

Recap:
Distributed algorithms

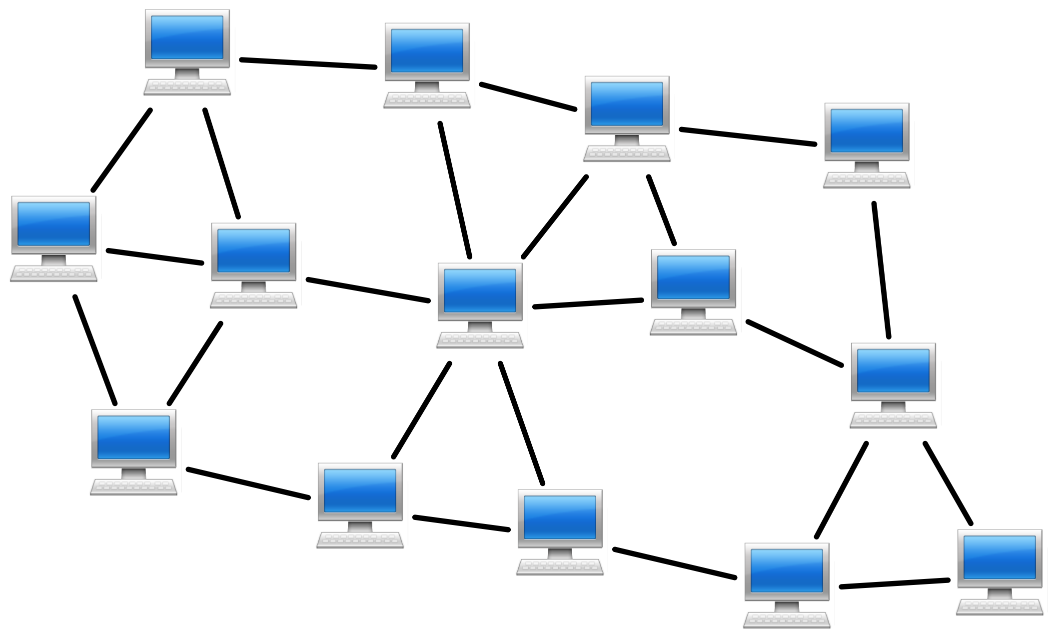
Algorithms for computer networks



Recap:

Distributed algorithms

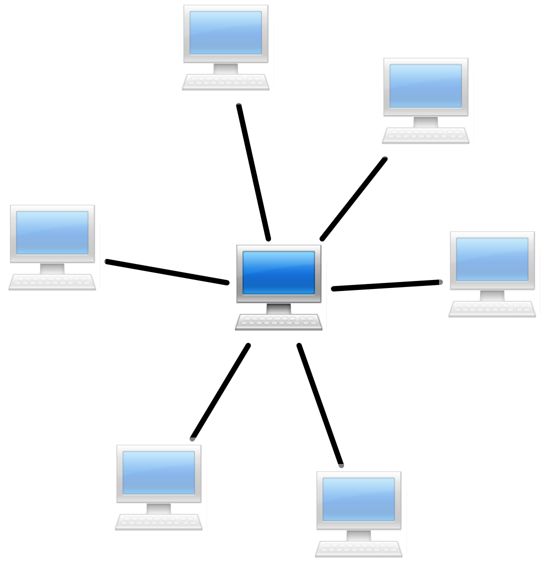
Identical computers in an unknown network, all running the same algorithm



Recap:

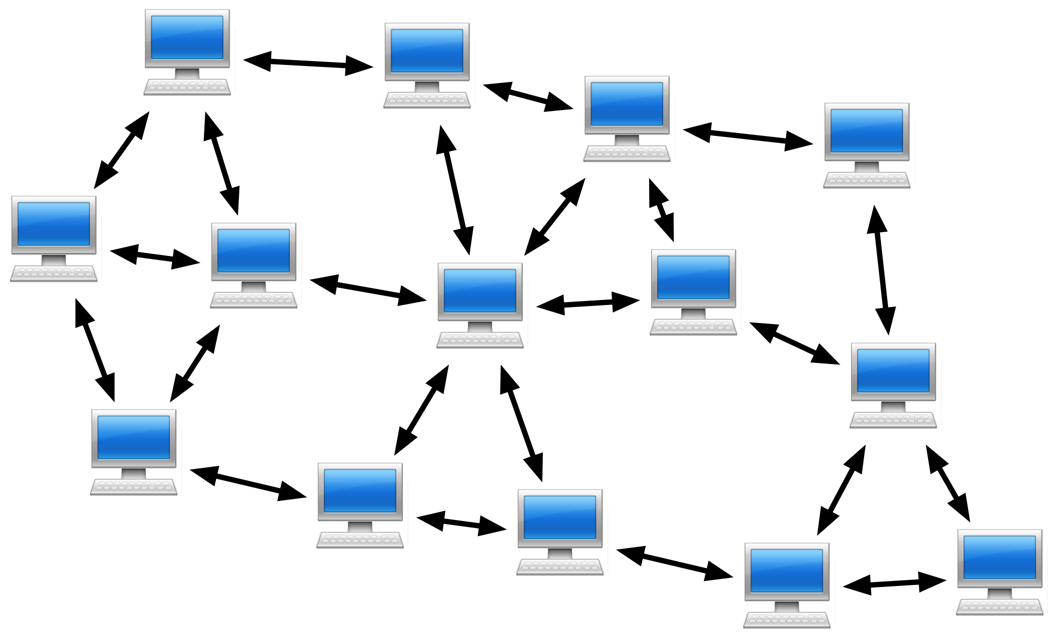
Distributed algorithms

Initially each computer only aware of its immediate neighbourhood



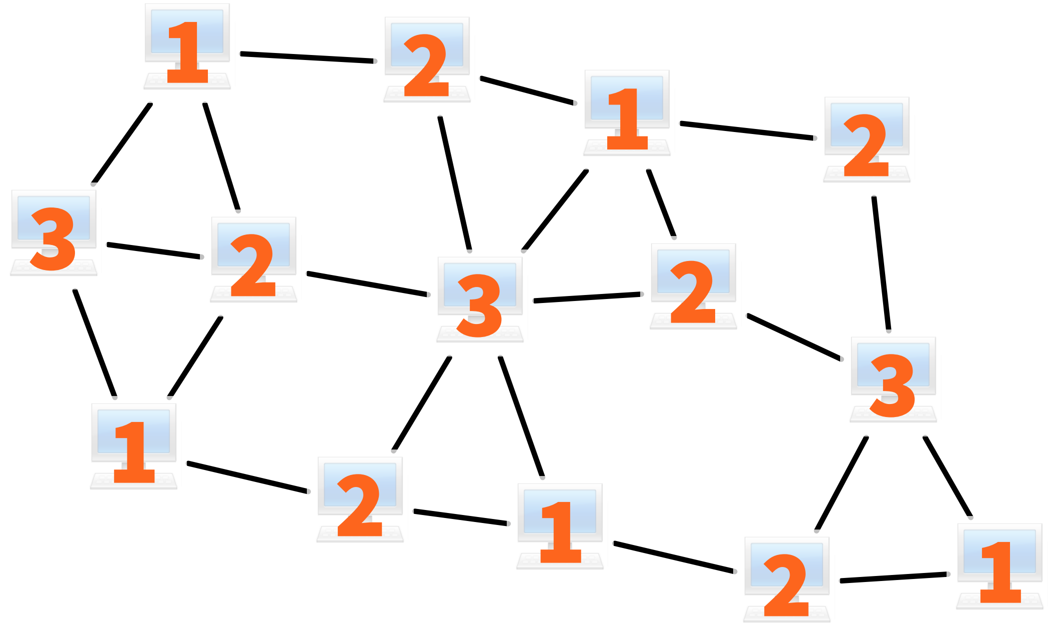
Recap:
Distributed algorithms

Nodes can exchange messages with their neighbours to learn more...



Recap:
Distributed algorithms

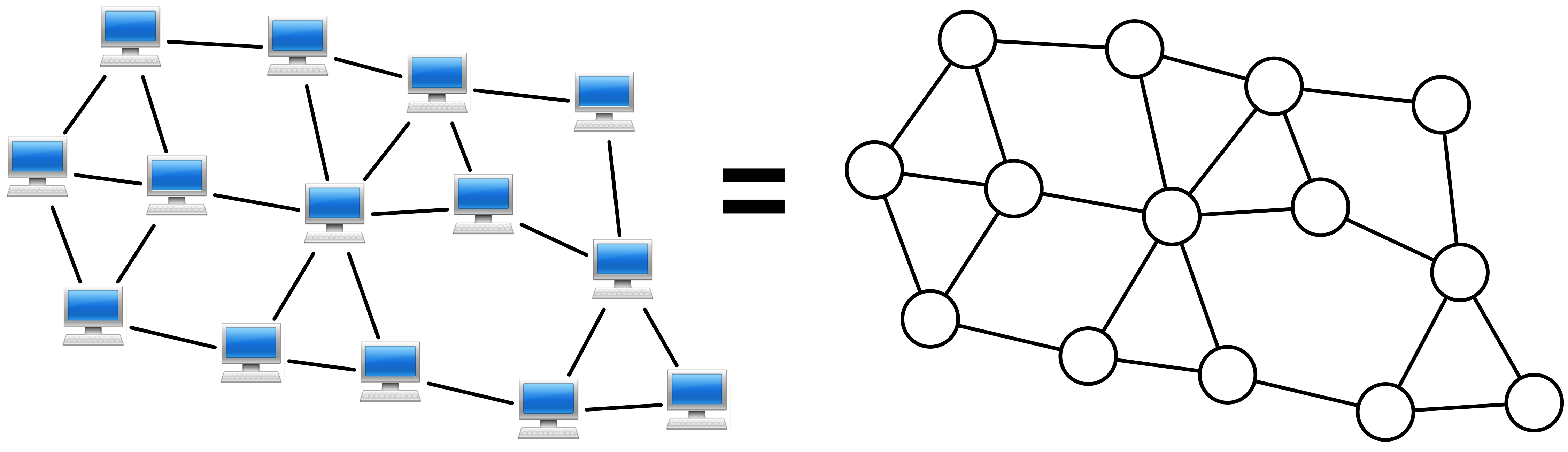
Finally, each computer has to stop and produce its own local output



Recap:

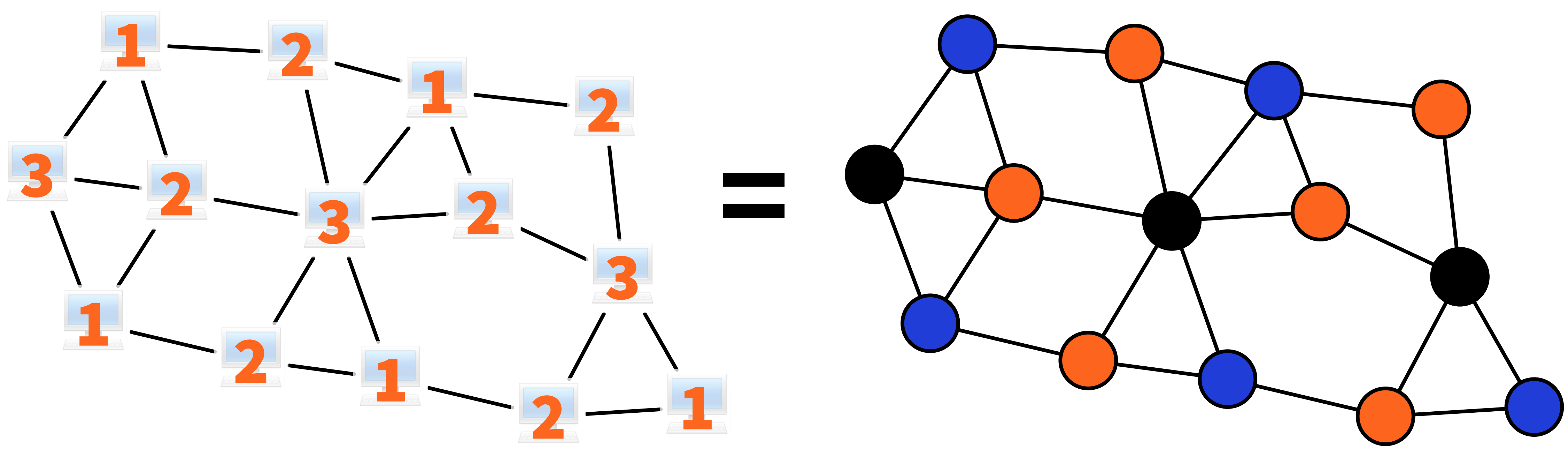
Distributed algorithms

Focus on graph problems:
network topology = input graph



Recap:
Distributed algorithms

Focus on graph problems:
local outputs = solution (here: graph colouring)



Recap:
Distributed algorithms

Typical research question:

“How fast can we solve graph problem X?”

Time = number of communication rounds

What have we learned?

- **Dealing with *unknown systems***
- **Dealing with *partial information***
- **Dealing with *parallelism***
- **Applications beyond distributed computing:** fault tolerance, online, streaming, multicore…

Learning objectives

- **Models**
- **Algorithms**
- **Lower bounds**
- **Graph theory**

Objective 1:
Models of computing

- **Precisely what is a *"distributed algorithm"***
- **In each of these models:**
  - PN, LOCAL, CONGEST
  - deterministic, randomised

Objective 2: **Algorithms**

- **Colouring paths:** LOCAL, $O(\log^* n)$
- **Colouring graphs:** LOCAL, $O(\log n)$ w.h.p.
- **Gather everything:** LOCAL, $O(\mathrm{diam}(G))$
- **Bipartite maximal matching:** PN, $O(\Delta)$
- **All-pairs shortest paths:** CONGEST, $O(n)$

Algorithm P3CBit: **Fast colour reduction**

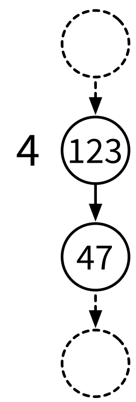
$\boldsymbol{c_0} = \mathbf{123} = \mathbf{01111\textcolor{orange}{0}11_2}$ (my colour)

$\boldsymbol{c_1} = \mathbf{47} = \mathbf{00101\textcolor{orange}{1}11_2}$ (successor's colour)

$\boldsymbol{i} = \mathbf{\textcolor{orange}{2}}$ (bits numbered 0, 1, 2, … from right)

$\boldsymbol{b} = \mathbf{\textcolor{orange}{0}}$ (in my colour bit number i was 0)

$\boldsymbol{c} = \mathbf{2 \cdot 2 + 0 = 4}$ (my new colour)



$k = 8$, reducing from $2^8 = 256$ to $2 \cdot 8 = 16$ colours

Algorithm P3CBit:
Fas

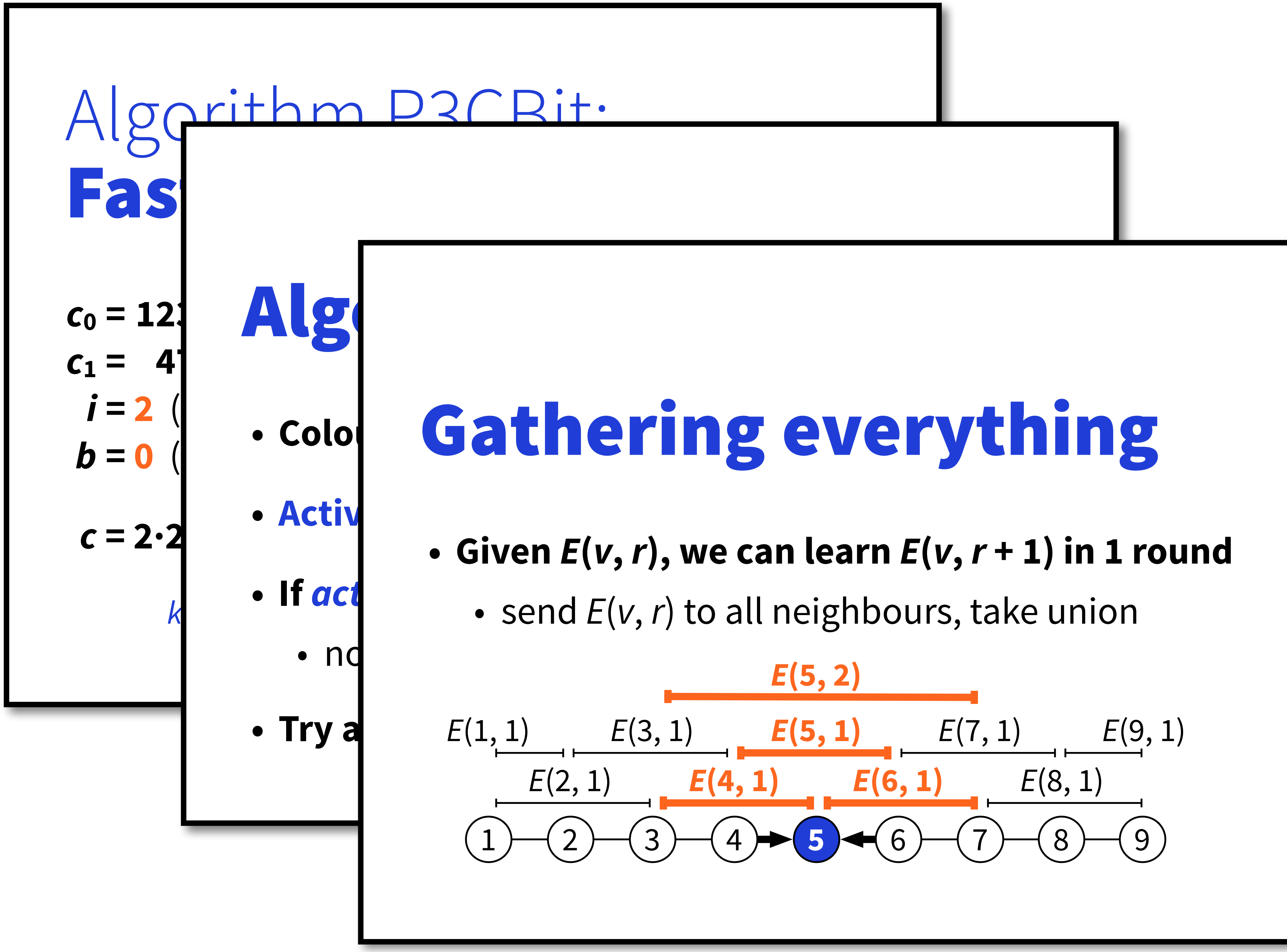
c_0 = 12
c_1 = 4
i = 2 (
b = 0 (

c = 2·2

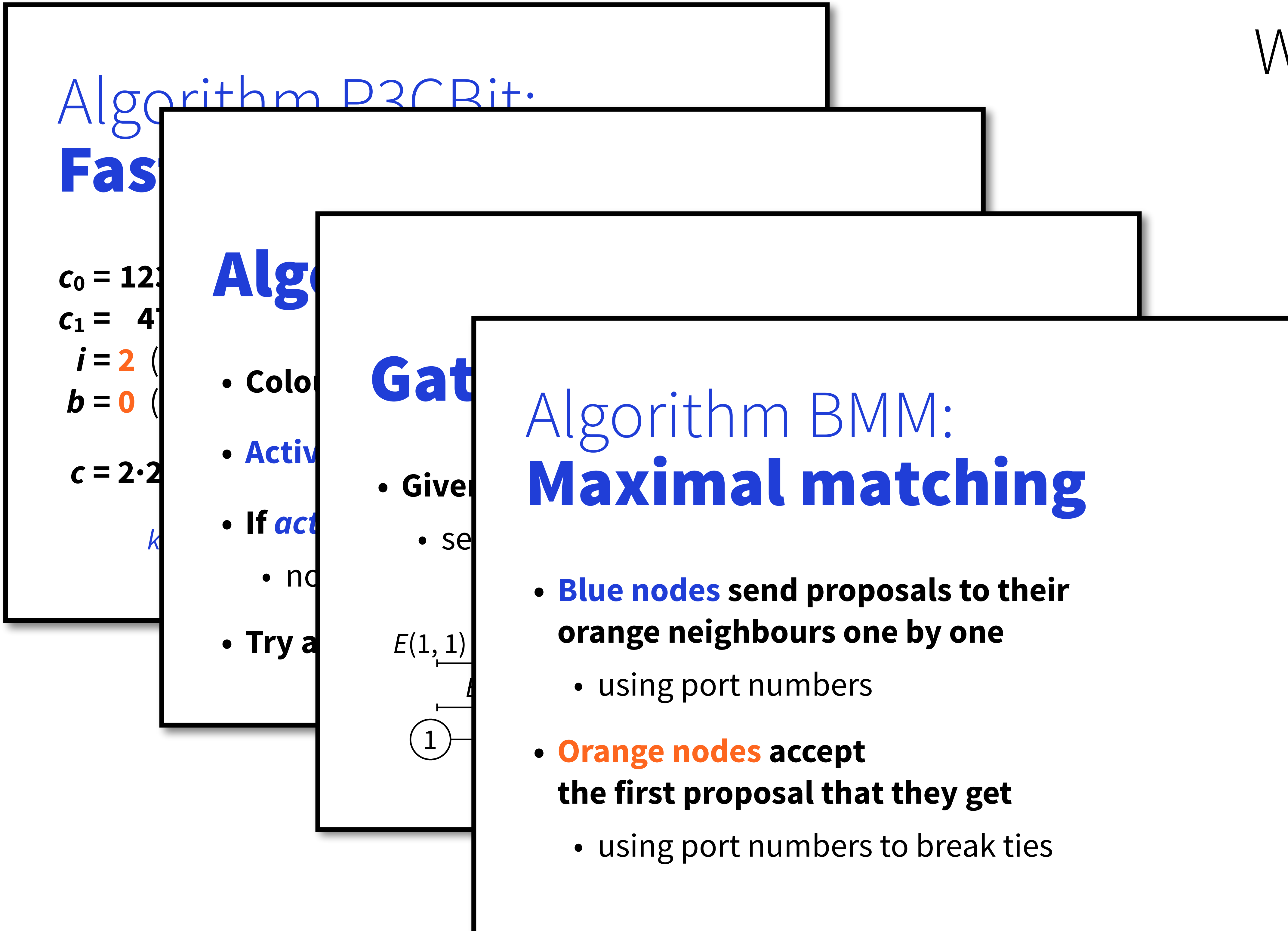
Algorithm idea 3

- **Colour palette: {1, 2, …, Δ + 1}**
- **Active with probability 1/2**
- **If *active*, pick a random *free* colour**
    - not used by any neighbour that has stopped
- **Try again if conflicts…**

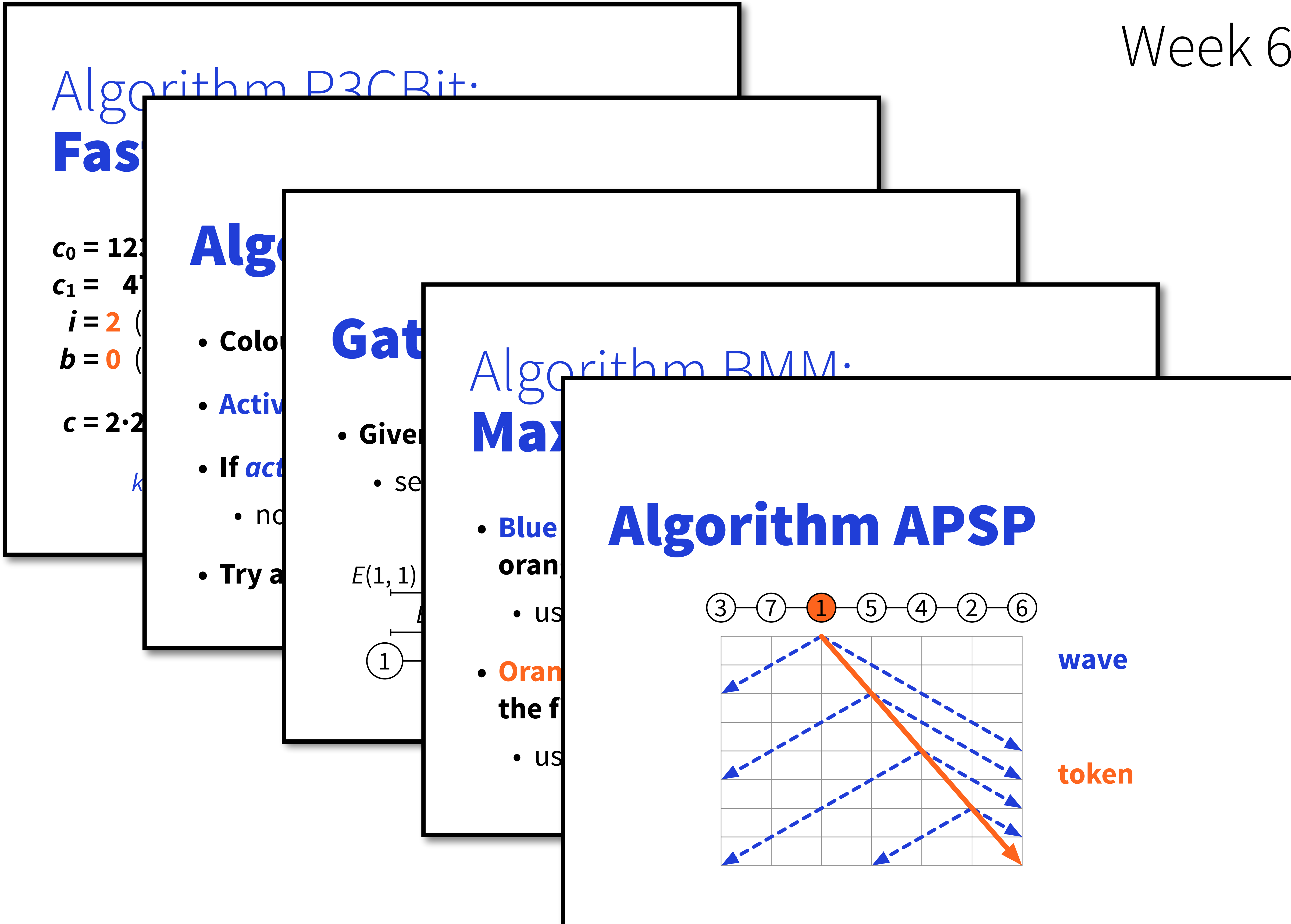
Week 5


Gathering everything
Given E(v, r), we can learn E(v, r + 1) in 1 round
send E(v, r) to all neighbours, take union
E(5, 2)
E(1, 1)
E(3, 1)
E(5, 1)
E(7, 1)
E(9, 1)
E(2, 1)
E(4, 1)
E(6, 1)
E(8, 1)
1
2
3
4
5
6
7
8
9

Week 4


Algorithm BMM:
Maximal matching
Blue nodes send proposals to their orange neighbours one by one
using port numbers
Orange nodes accept the first proposal that they get
using port numbers to break ties

Week 6



Objective 2:
Algorithms

- **Reductions!**

- **Graph colouring is a very useful subroutine**

Objective 3:
Lower bounds

- **Covering maps:**
  what cannot be solved at all in PN model
- **Local neighbourhoods:**
  what cannot be solved fast in any model
- **Ramsey's theorem:**
  what cannot be solved in $O(1)$ time

Objective 4:
Graph theory

- **Basic definitions**
- **Connections between graph problems**
  - e.g. maximal matching → small vertex covers
- **Ramsey's theorem**
  - at least for $c = 2$, $k = 2$

What else is studied in distributed computing?

- Fault-tolerance
- Asynchrony
- Shared memory
- Physical models
- Robot navigation
- Nondeterminism
- Complexity measures
- High-performance computing
- Practical aspects of networking …

What next?

- **CS-E4580 Programming Parallel Computers**
  - 5th period, 5 credits, intensive course
  - programming modern parallel computers: multicore, GPU, memory hierarchies …
  - hands-on programming exercises
  - main goal: make it as fast as you can!

What next?

- **Just ask if you want to do more!**
  - Master's thesis topics?
  - summer internships?
  - doctoral studies?

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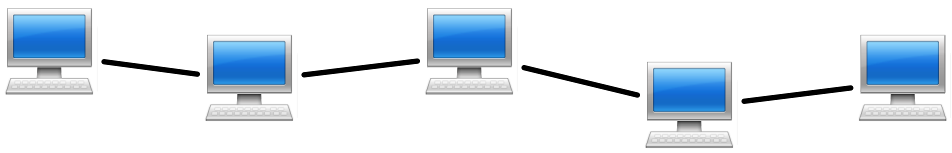
  - network = path 
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