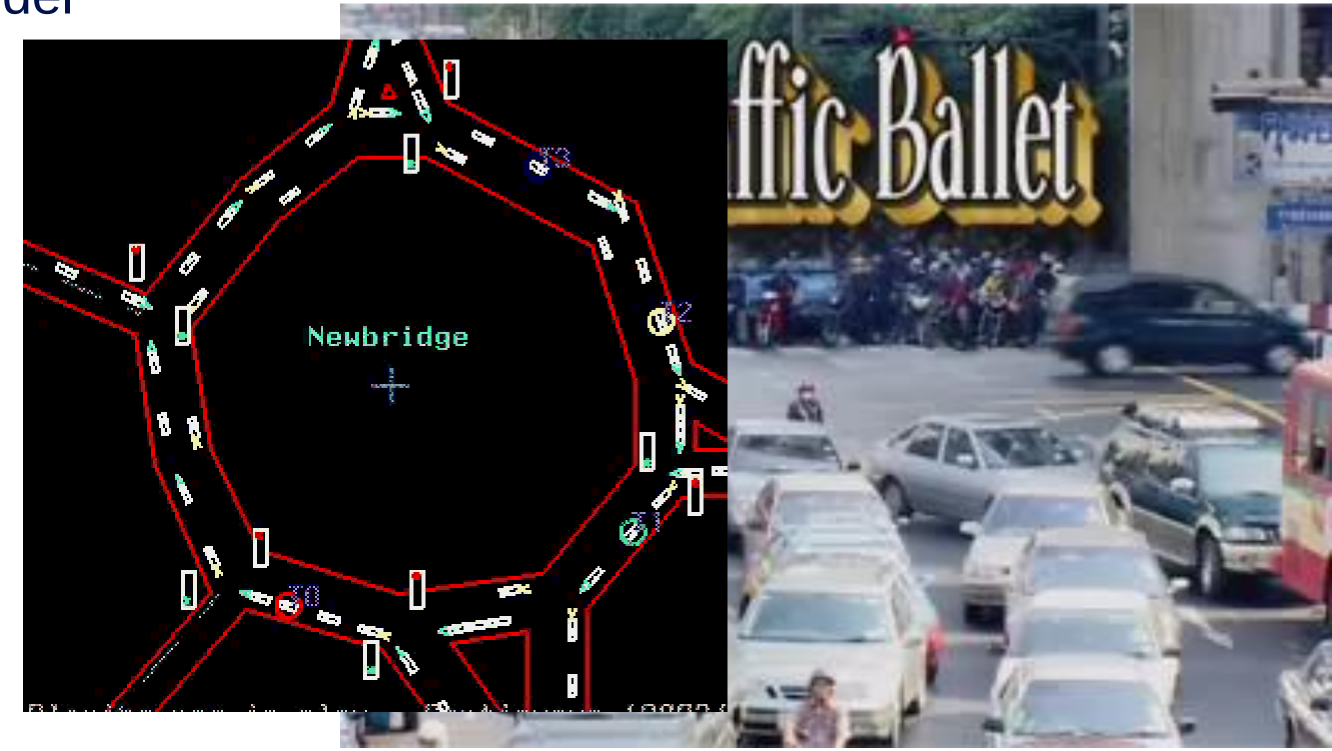
Parallel Programming

Thought exercise: traffic modelling

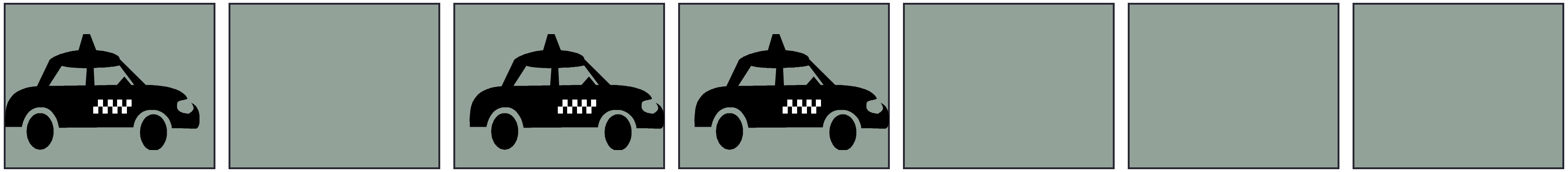
Traffic Flow

- we want to predict traffic flow
  - – to look for effects such as congestion
- build a computer model



Simple Traffic Model

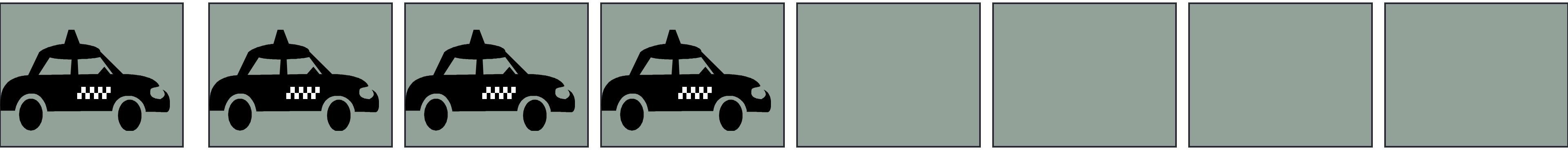
- divide road into a series of cells
  - either occupied or unoccupied
- perform a number of steps
  - each step, cars move forward if space ahead is empty

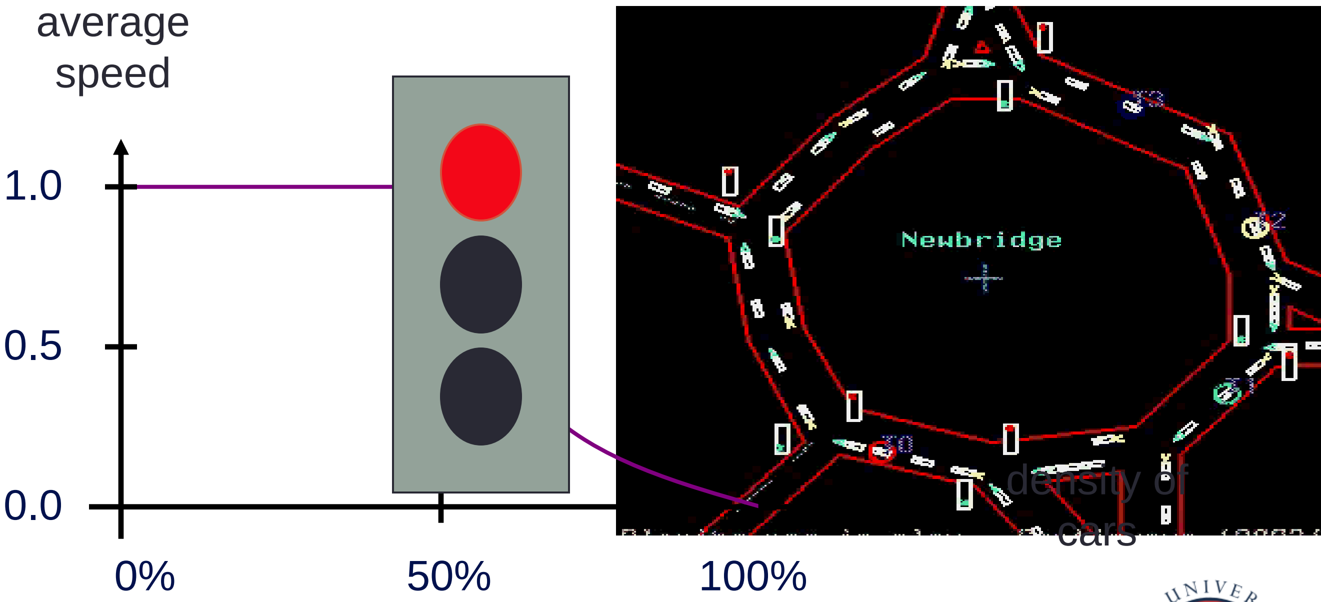


could do this by moving pawns on a chess board

traffic behaviour

- model predicts a number of interesting features
  - traffic lights

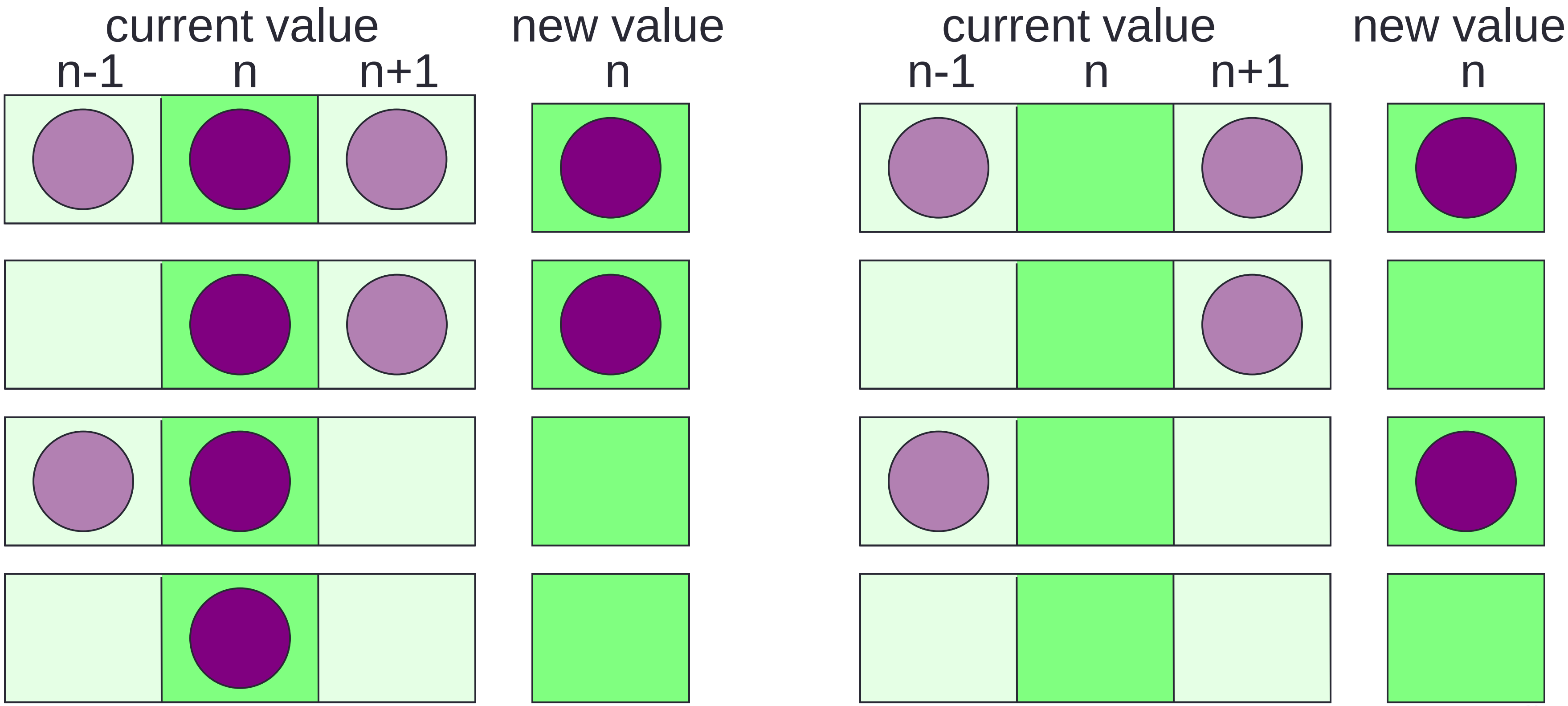




- congestion
- more complicated models are used in practice

Traffic simulation

- Update rules depend on:
  - state of cell
  - state of nearest neighbours in both directions



State Table

- If $R^t(i) = 0$, then $R^{t+1}(i)$ is given by:

	$R^t(i-1) = 0$	$R^t(i -1) = 1$
$R^t(i+1) = 0$	0	1
$R^t(i+1) = 1$	0	1

- If $R^t(i) = 1$, then $R^{t+1}(i)$ is given by:

	$R^t(i-1) = 0$	$R^t(i -1) = 1$
$R^t(i+1) = 0$	0	0
$R^t(i+1) = 1$	1	1

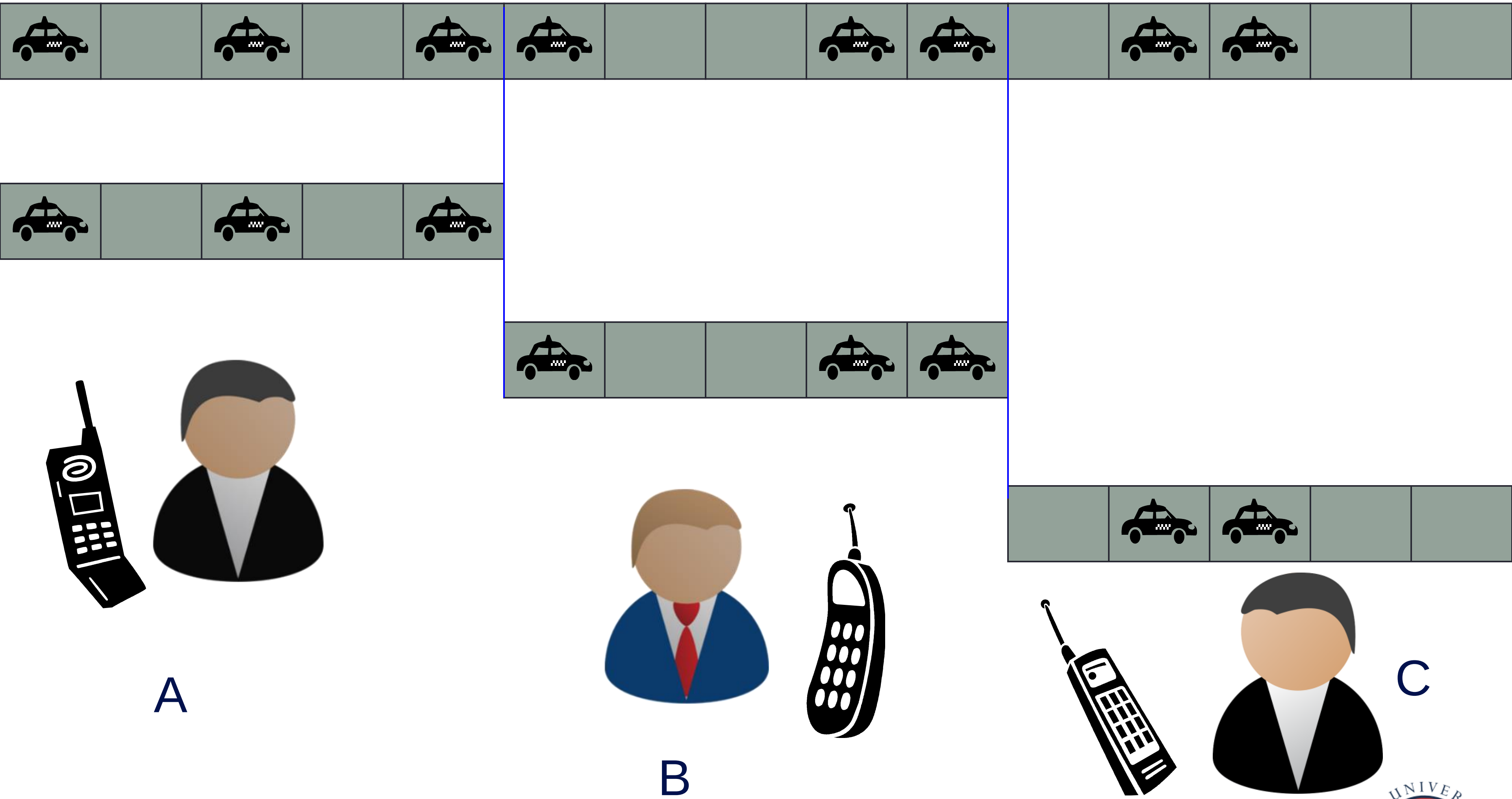
Pseudo Code

```
declare arrays old(i) and new(i), i = 0,1,...,N,N+1
initialise old(i) for i = 1,2,...,N-1,N (eg randomly)
loop over iterations
  set old(0) = old(N) and set old(N+1) = old(1)
  loop over i = 1,...,N
    if old(i) = 1
      if old(i+1) = 1 then new(i) = 1 else new(i) = 0
    if old(i) = 0
      if old(i-1) = 1 then new(i) = 1 else new(i) = 0
  end loop over i
  set old(i) = new(i) for i = 1,2,...,N-1,N
end loop over iterations
```

how fast can we run the model?

- measure speed in Car Operations Per second
  - how many COPs?
- around 2 COPs
- but what about three people?
  - can they do six COPs?

a parallel traffic model



Pseudo Code (with subroutines)

```
 declare arrays old(i) and new(i), i = 0,1,...,N,N+1
 initialise old(i) for i = 1,2,...,N-1,N (eg randomly)
 loop over iterations
!  Implement boundary conditions
   set old(0) = old(N) and set old(N+1) = old(1)
!  Update road
     call newroad(new, old, N)
!  Prepare for next iteration
   set old(i) = new(i) for i = 1,2,...,N-1,N
 end loop over iterations
```

Pseudo Code (distributed memory)

```
!  assume we are running on P processes
 declare arrays old(i) and new(i), i = 0,1,...,N/P,N/P+1
 initialise old(i) for i = 1,2,...,N/P-1,N/P (eg randomly)
 loop over iterations
!   Implement boundary conditions (processes arranged as a ring)
    set old(0) on this process to old(N/P) from previous process
    set old(N/P+1) on this process to old(1) from next process
!   Update road
      call newroad(new, old, N/P)
!   Prepare for next iteration
    set old(i) = new(i) for i = 1,2,...,N/P-1,N/P
 end loop over iterations
```

Halo swapping

```
! Implement boundary conditions
  set old(0) on this process to old(N/P) from previous process
  set old(N/P+1) on this process to old(1) from next process
```

- Implement this using blocking receives (e.g. MPI_Recv) and:
  - synchronous send (routine blocks until message is received)
  - e.g. MPI_Ssend
- or
  - asynchronous send (message copied into buffer, returns straight away)
  - e.g. MPI_Bsend
- or
  - non-blocking synchronous send (no buffering but immediate return)
  - e.g. MPI_Issend / MPI_Wait

Synchronous sends

```
! Implement boundary conditions
   Ssend(old(N/P),   up)
   Recv (old(1),   down)
   Ssend(old(1),   down)
   Recv (old(N/P+1), up)
```

- Guaranteed to deadlock

Asynchronous (buffered) sends

```
Bsend(old(N/P),   up)
Recv (old(1),    down)
Bsend(old(1),    down)
Recv (old(N/P+1), up)
call newroad(new, old, N/P)
set old(i) = new(i) for i = 1,2,...,N/P-1,N/P
```

- Where do synchronisation issues become important?

  ```
  call newroad(new, old, N/P) ?
  ```

  - OK because we are writing new but only reading old
  - **`set old(i) = new(i) ?`**
  - only OK because **`Bsend`** has copied **`old(1)`** and **`old(N/P)`**
- We **don't** really care if/when the message is received
  - we **do** really care if/when we can safely reuse the local send buffers

Standard sends

```
Send(old(N/P),   up)
Recv (old(1),   down)
Send(old(1),   down)
Recv (old(N/P+1), up)
call newroad(new, old, N/P)
set old(i) = new(i) for i = 1,2,...,N/P-1,N/P
```

- *Might* deadlock
  - MPI_Send can be implemented as synchronous send (MPI_Ssend) or buffered send (MPI_Bsend) *but you do not know which*

- In practice
  - buffered for small messages
  - synchronous for large messages

Non-blocking (immediate) sends

```
! Implement boundary conditions
   Issend(old(N/P),   up)
   Recv  (old(1),   down)
   Issend(old(1),   down)
   Recv  (old(N/P+1), up)
   call newroad(new, old, N/P)
   set old(i) = new(i) for i = 1,2,...,N/P-1,N/P)
! Wait for communications to complete before next iteration
   wait(up)
   wait(down)
```

- Incorrect!
  - overwriting old is the key issue
  - need to know boundary values of old are sent before overwriting

Non-blocking sends: correct

```
! Implement boundary conditions
   Issend(old(N/P),   up)
   Recv  (old(1),   down)
   Issend(old(1),   down)
   Recv  (old(N/P+1), up)
   call newroad(new, old, N/P)
   wait(up)
   wait(down)
   set old(i) = new(i) for i = 1,2,...,N/P-1,N/P)
```

Delaying the waits

```
! Implement boundary conditions
   Issend(old(N/P),   up)
   Recv  (old(1),   down)
   Issend(old(1),   down)
   Recv  (old(N/P+1), up)
   call newroad(new, old, N/P)
   set old(i) = new(i) for i = 2,3,...,N/P-1)
   wait(up)
   old(N/P = new(N/P)
   wait(down)
   old(1) = new(1)
```