Parallel Computing for Science & Engineering SSC 374/394c

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The ideas of parallel programming

- As illustrated by Conway's *Game of Life*
- http://youtu.be/C2vgICfQawE

- This has the same structure as certain important applications (e.g., PDEs) but requires no math to explain.
- Note: this is about parallel *programming*, not so much about parallel *hardware*

How do you code this?

- First the function for updating a single cell

```
def life_evaluation( cells ):
  # cells is a 3x3 array
  count = 0
  for i in [0,1,2]:
    for j in [0,1,2]:
      if i!=1 and j!=1:
        count += cells[i,j]
  cells[1,1] = life_count_evaluation(count )

def life_count_evaluation( count ):
  # big if statement
  return newval
```

How do you code this?

- Now to update the whole board
- One time-stepping loop
- Two loops for the board

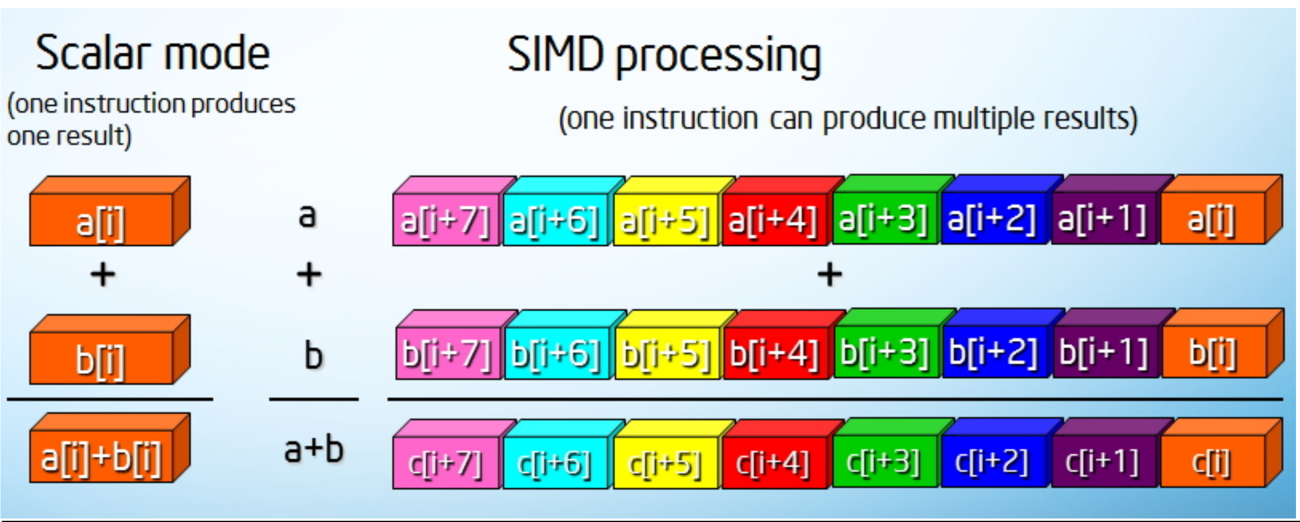
```
life_board.create(final_time,N,N)

for t in [0:final_time-1]:
  for i in [0:N-1]:
    for j in [0:N-1]:
      life_board[t+1,i,j]  :=
         life_evaluation(life_board
                  [t,i-1:i+1,j-1:j+1]  )
```

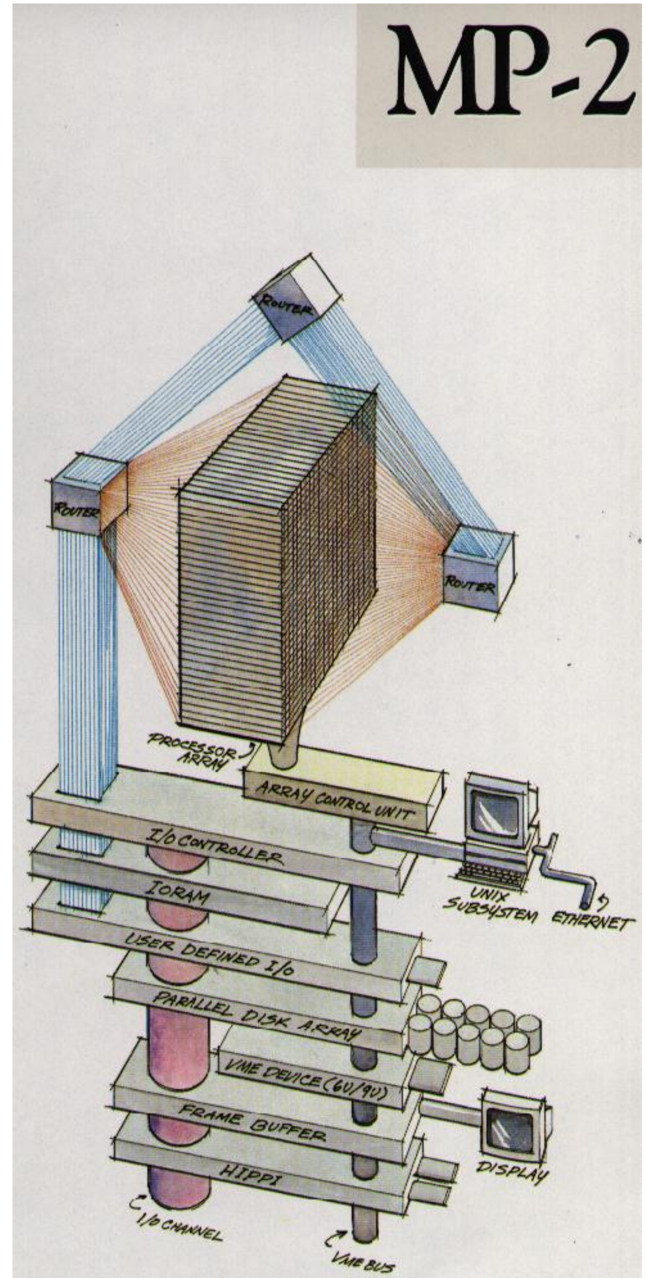
Where does parallelism come from?

- The program text specifies a sequence of operations
- However, some operations can be done in any order
- => so they can also be done simultaneously
- There are no compilers that recognize this, so you have to code it by hand
  and that's what you will learn here….

Data parallelism

- Independent data items, each undergoing the same operation
- Then: “array processors”
- Now: vector instructions





SIMD parallelism

- Single Instruction Multiple Data
- Simplified instruction handling: only one instruction fetch/decode/whatever for multiple data items
- Need to have many independent operations (examples?)
- Data storage may need to be regular

Example: GPUs

- Graphical Processing Units are SIMD-like (not completely lockstep)
- Programmed in CUDA:
  kernel contains sequential code,
  kernel is executed in parallel

```
kerneldef  life_step(  board  ):
     i = my_i_number()
     j = my_j_number()
     board[i,j]  = life_evaluation
                ( board[i-1:i+1,j-1:j+1]  )

for t in [0:final_time]:
     <<N,N>>life_step(  board  )
```

Parallel programming may mess up your code!

- Parallelism on the instruction level: innermost loop
- Sometimes loop exchange needed

```
for i=1,N:
  for j=1,N:
    count = 0
    for h in [-1,0,1]:
      for v in [-1,0,1]:
        count += cell[i+v,j+h]
```

```
for i=1,N:
  for j=1,N:
    count[i,j] = 0
for h in [-1,0,1]:
  for v in [-1,0,1]:
    for i=1,N:
      for j=1,N:
        count += cell[i+v,j+h]
```

Minimal intervention: loop parallelism

- Loops are an important source of parallelism
- Parallelize by indicating what loops parallel

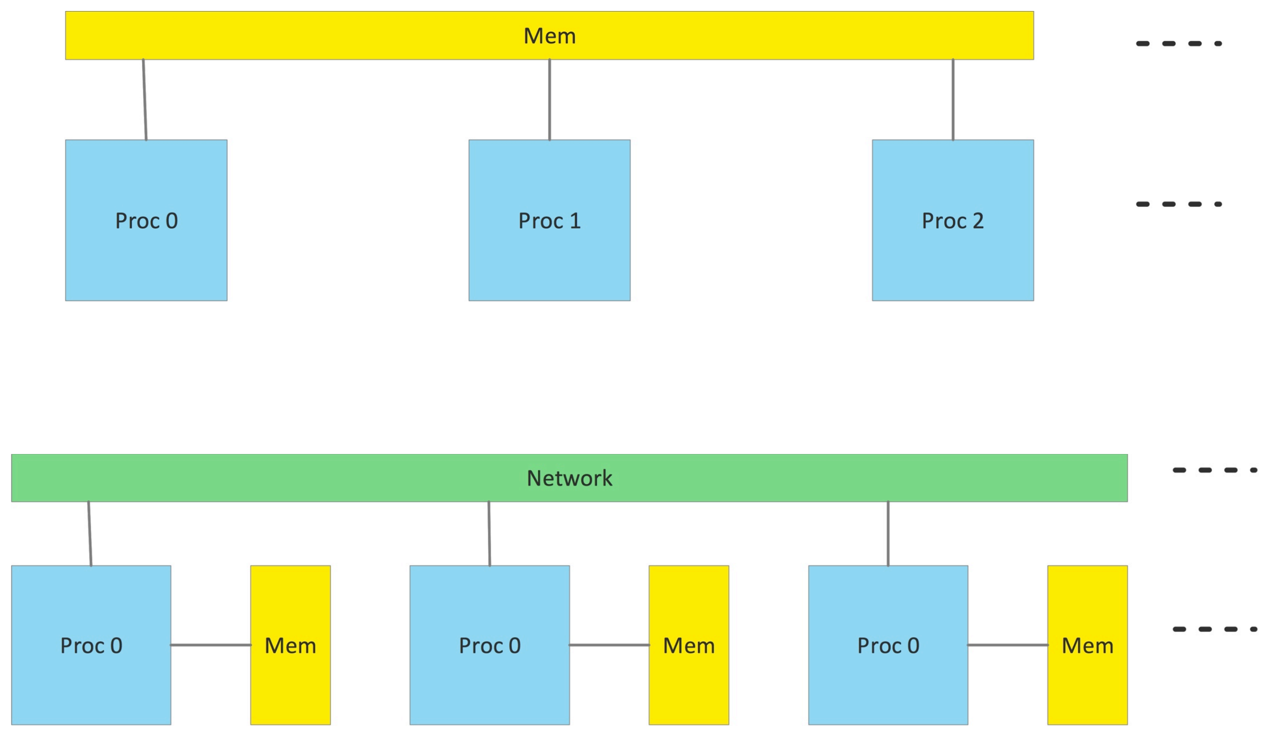
```
def life_generation( board,tmp ):
  # OMP parallel for
  for i in [0:N-1]:
    for j in [0:N-1]:
      tmp[i,j] = board[i,j]
  # OMP parallel for
  for i in [0:N-1]:
    for j in [0:N-1]:
      board[i,j] = life_evaluation
        ( tmp[i-1:i+1,j-1:j+1] )
```

Granularity of parallelism

- So far: independence of single operations / single data points:
  fine-grained parallelism
- Locality: points close together should be handled by the same processor
- Process the board by lines or subparts:
  coarse-grained parallelism

Why coarse-grained parallelism?

- Shared memory: every processor can find every data item
- Distributed memory: some data is local, other not
- Locality

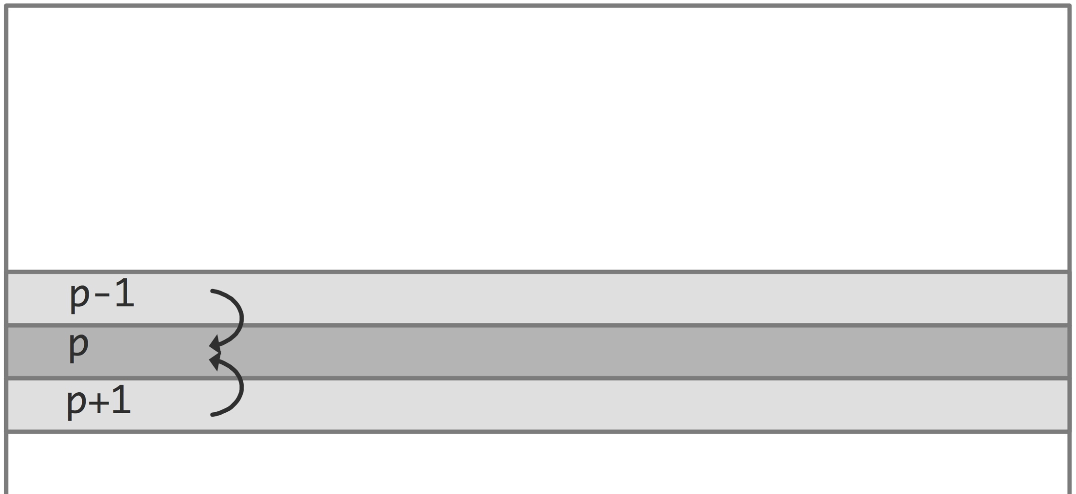


What does distributed memory look like?

- Stampede
- 160 cabinets, 6400 nodes, 500k cores….

How do you program distributed memory?

- Explicit message passing




```
p = my_processor_number()

high_line  = MPI_Receive(from=p-1,cells=N)
low_line = MPI_Receive(from=p+1,cells=N)

tmp_line = my_line.copy()
my_line = life_line_update(high_line,tmp_line,low_line,N)
```

No, really…..

- You can’t receive without someone else sending
- But the someone else is running the same program…
- Single Program Multiple Data:
  each processor runs the same program,
  just on different data:
- Execution differs in:
  loop bounds,
  branches of conditionals

Two-sided message passing

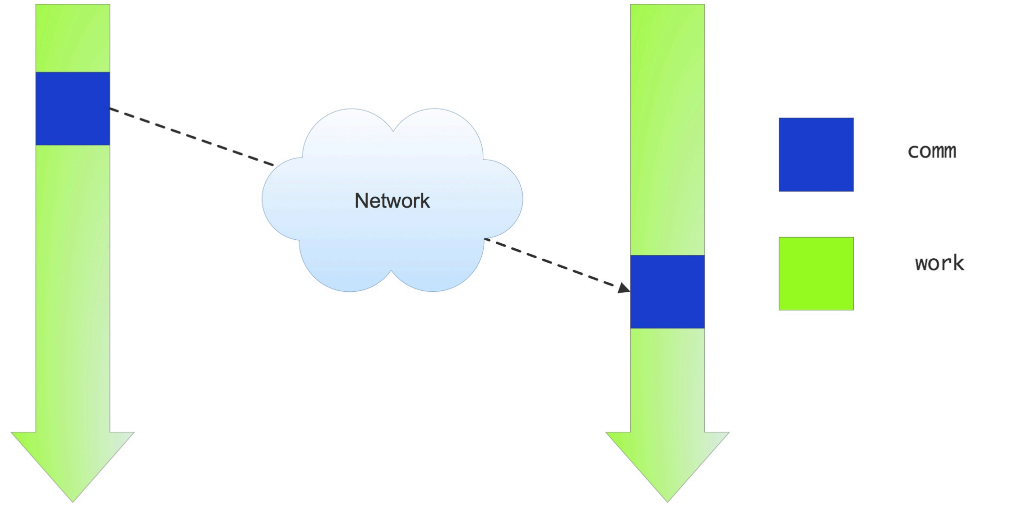
- Everyone does both send and receive calls
- Attempt at coding this:

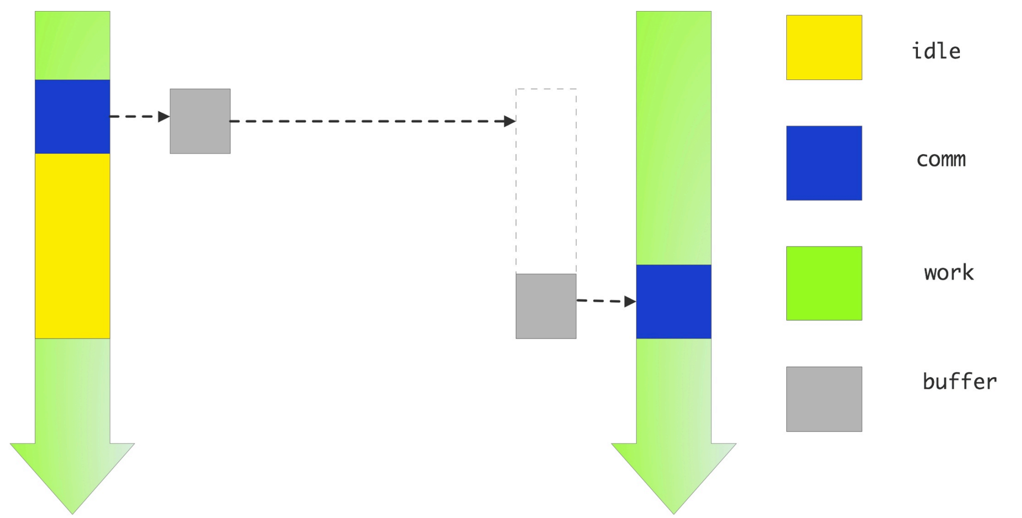
- And even this is not correct

```
p = my_processor_number()

# send my data
my_line.MPI_Send(to=p-1,cells=N)
my_line.MPI_Send(to=p+1,cells=N)

# get data from neighbours
high_line  = MPI_Receive(from=p-1,cells=N)
low_line  = MPI_Receive(from=p+1,cells=N)
tmp_line  = my_line.copy()

# do the local computation
my_line  = life_line_update
        (high_line,tmp_line,low_line,N)
```

Blocking communication

- Data has to be somewhere
- You can only send if someone else receives
- Deadlock possible if everyone is receiving, no one is sending





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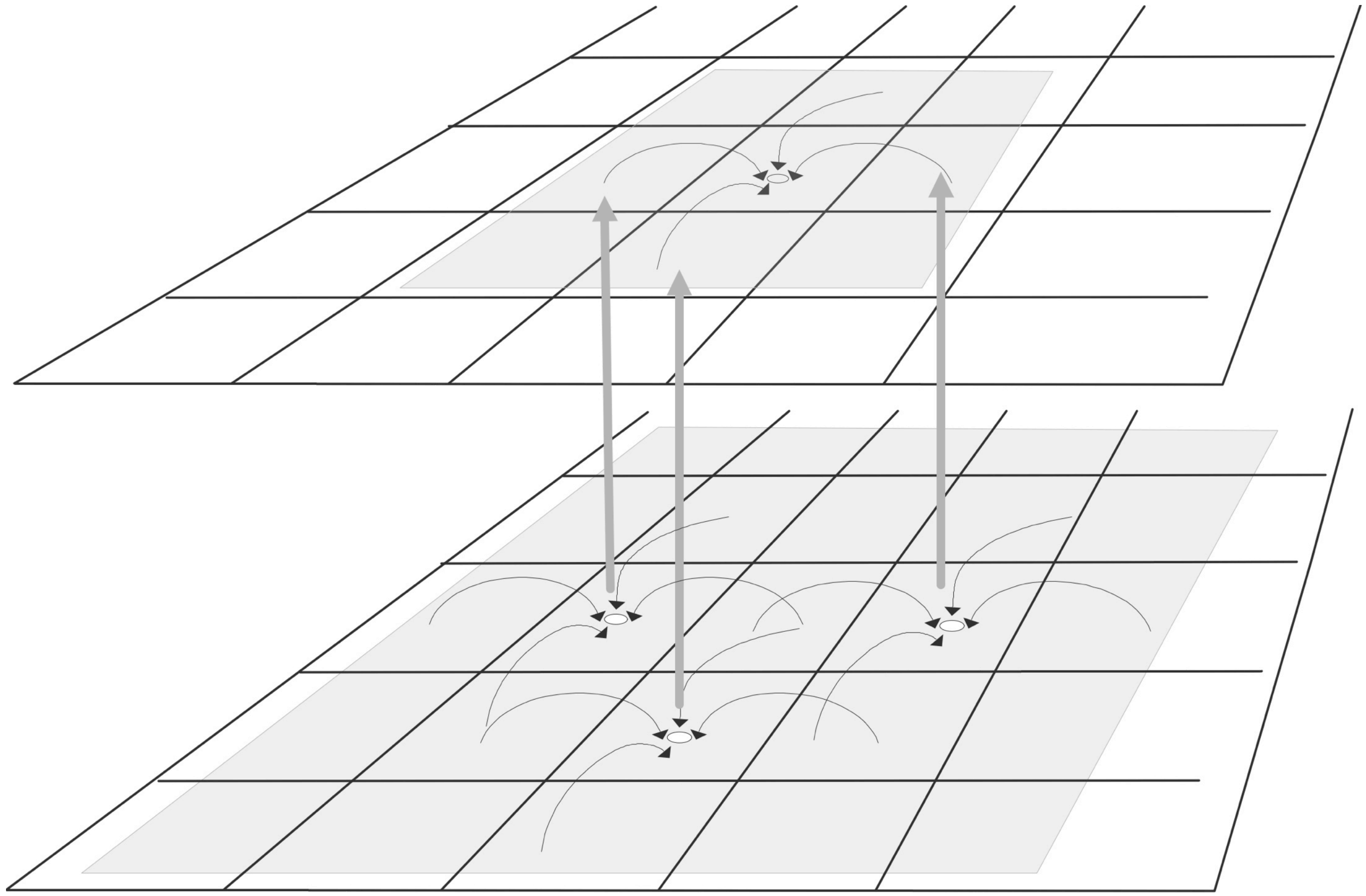
Task parallelism

- Think about instructions rather than data
- In the Game of Life there are $N^2 T$ updates
- How independent are they?

Life updates dependencies

- Cell needs a box around it
- Each cell in the box needs….
- => Cone of influence



Task scheduling

- User indicates dependencies
- Algorithm under the hood matches available tasks to available processors/cores

```
while there_are_tasks_left():
  for r in running_tasks:
    if r.finished():
      for t in scheduled_tasks:
        t.mark_input_available(r)
    t = find_available_task()
    p = find_available_processor()
    schedule(t,p)
```

```
for t in [0:T]:
  for i in [0:N]:
    for j in [0:N]:
      task( id=[t+1,i,j],
        prereqs=[
           [t,i,j],
           [t,i-1,j],
           [t,i+1,j]
           # et cetera
                ] )
```

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Summary

- SIMD / vector parallelism:
  very fine-grained
  vector instructions
- Loop-based parallelism:
  OpenMP directives
- Tasks:
  OpenMP tasks, medium grain
- Message passing:
  MPI, coarse grain