Computational Science on Many-Core Architectures

360.252

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Agenda for Today

Exercise 4 Recap (again)

Exercise 5 Recap

Maximum Independent Sets

Warp Shuffles

Exercise 6

Exercise 4 Recap

Just one more thing...

- `cudaMemcpy()` can kill performance

```
while ( /* CG not converged */ ) {
  cudaMemcpy(gpu_alpha, alpha, sizeof(double),
      cudaMemcpyHostToDevice);
  cudaMemcpy(gpu_Ap, Ap, sizeof(double),
      cudaMemcpyHostToDevice);
  cudaMemcpy(gpu_pp, pp, sizeof(double),
      cudaMemcpyHostToDevice);
  pipelinedKernel<<<.....>>>>(....);
  cudaMemcpy(alpha, gpu_alpha, sizeof(double),
      cudaMemcpyDeviceToHost);
  cudaMemcpy(Ap, gpu_Ap, sizeof(double),
      cudaMemcpyDeviceToHost);
  cudaMemcpy(pp, gpu_pp, sizeof(double),
      cudaMemcpyDeviceToHost);

  ...
}
```

Only one kernel, but 6 copies (with costs similar to a kernel launch)

Exercise 4 Recap

Just one more thing...

- `cudaMemcpy()` can kill performance

```
while ( /* CG not converged */ ) {
  cudaMemcpy(gpu_scalars, scalars, sizeof(double),
      cudaMemcpyHostToDevice);
  pipelinedKernel<<<.....>>>(....);
  cudaMemcpy(scalars, gpu_scalars, sizeof(double),
      cudaMemcpyDeviceToHost);

  ...
}
```

One kernel, two copies (first copy can sometimes be avoided)

Exercise 5 Recap

Feedback Time

- How was your experience?

Exercise 5 Recap

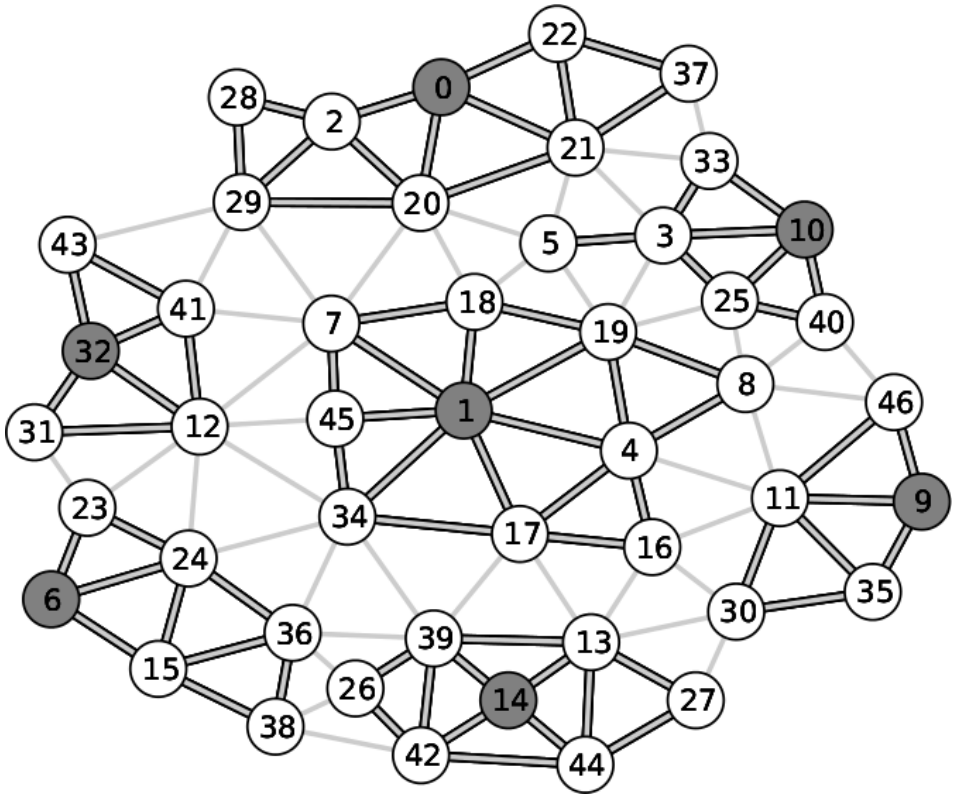
Feedback Time

- How was your experience?
- Most points for Exercise 4 should have been provided by now (4 missing).

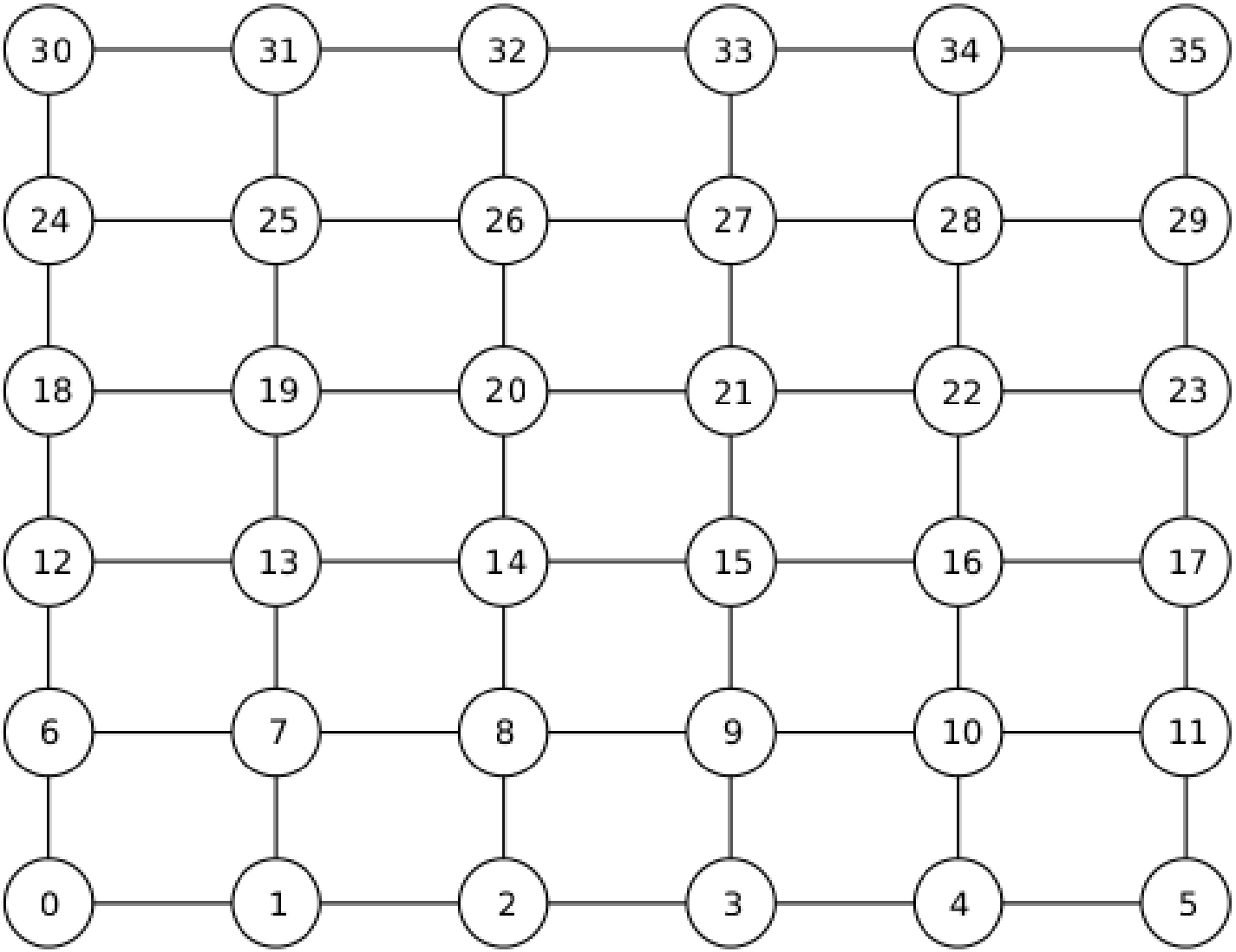
Maximum Independent Sets (MIS)

Splitting a Graph

- Decompose a connected graph into independent connected subsets
- MIS-d: At least d vertices between MIS nodes
- A formal definition is a bit tricky $\Rightarrow$ skipped
- Parallel construction: Luby's method (and variants thereof)

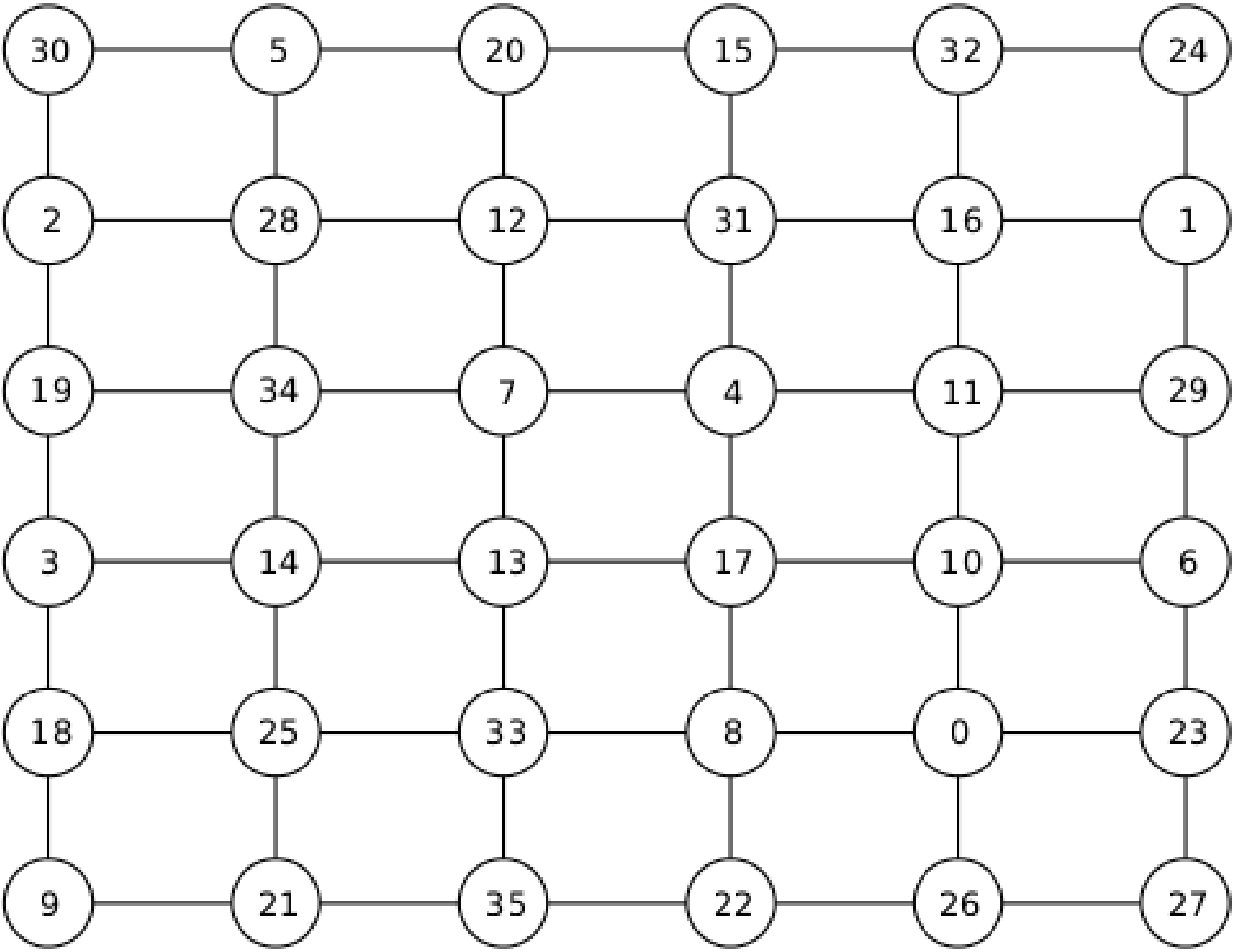


MIS-2 Construction



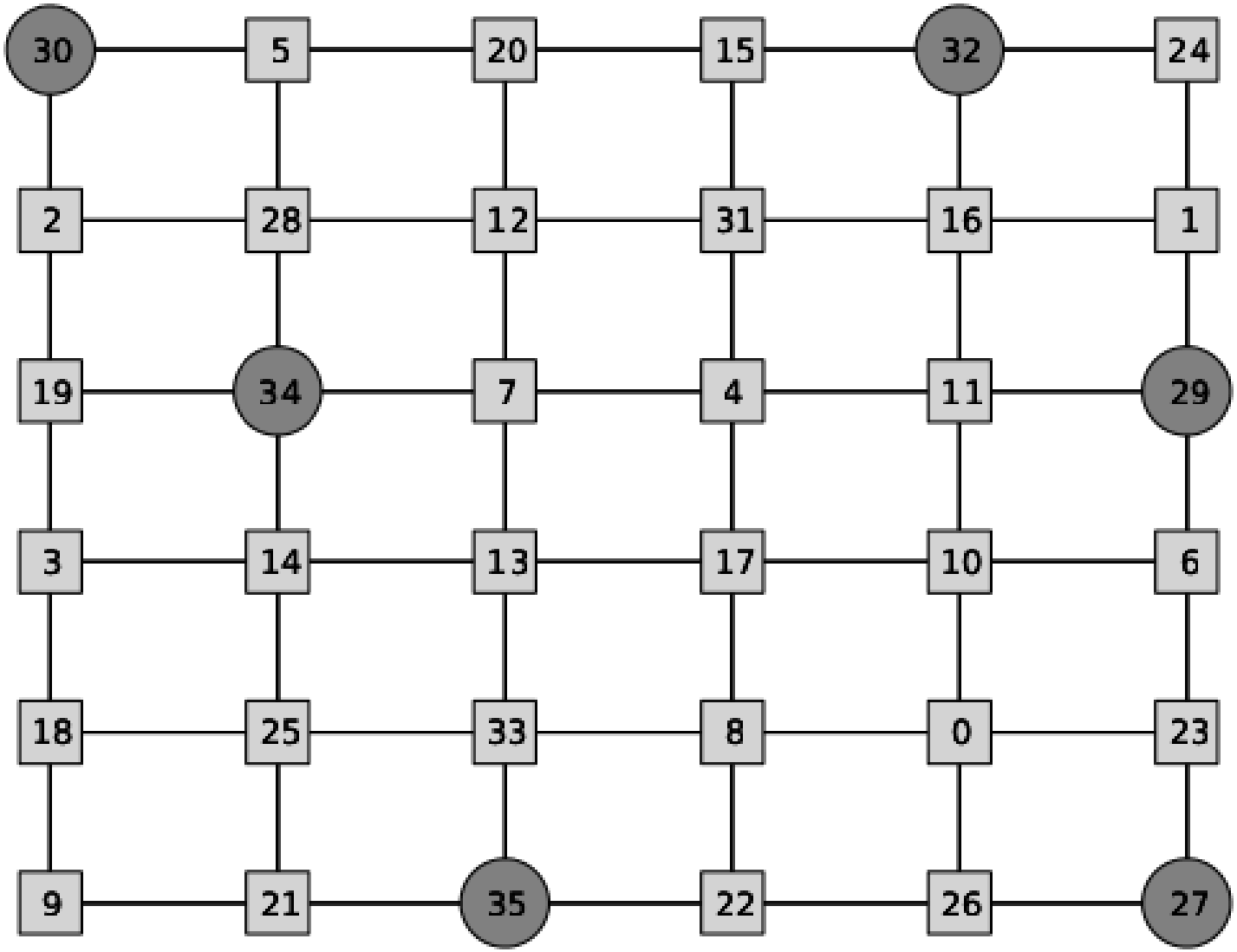
Initial grid

MIS-2 Construction



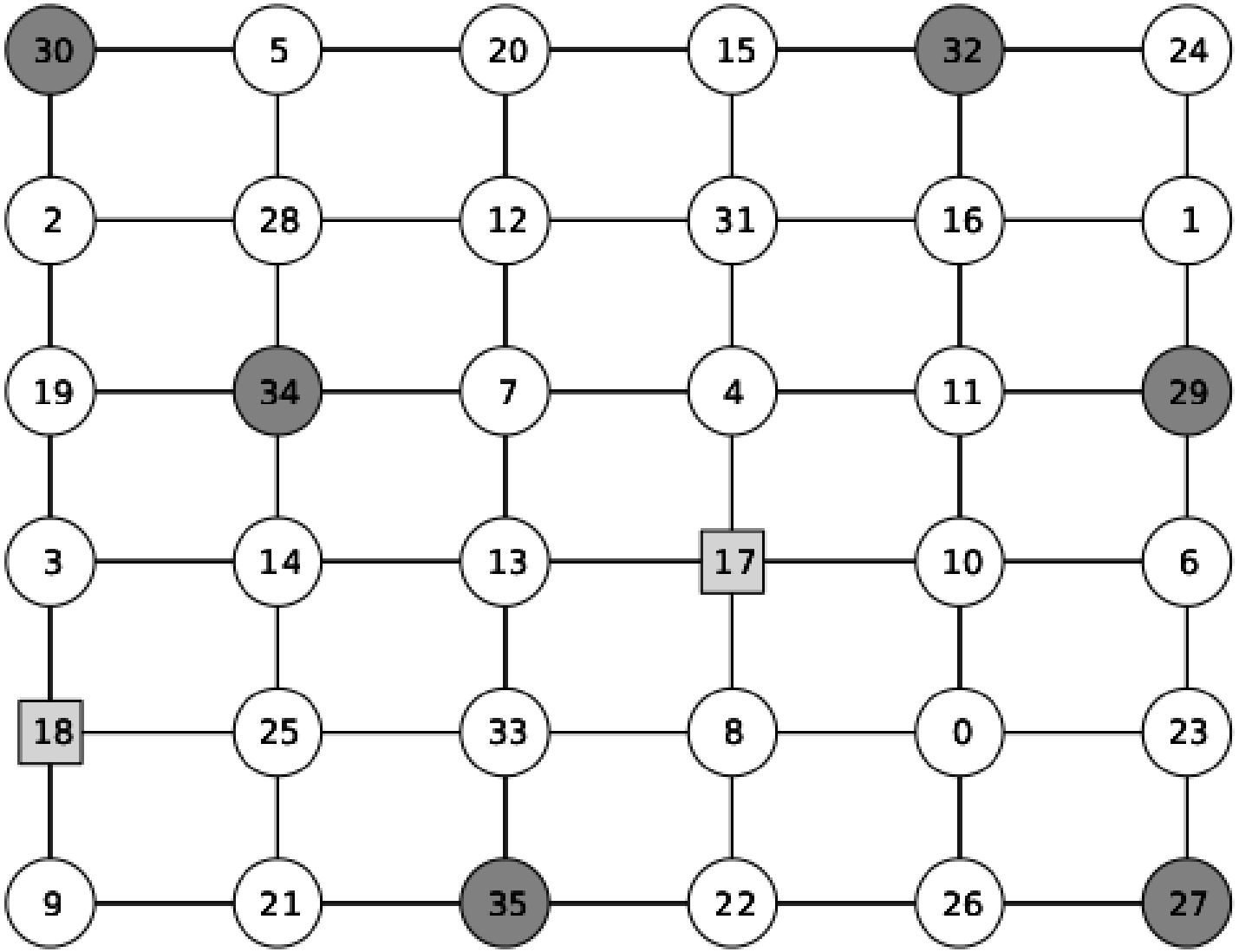
Randomize numbering

MIS-2 Construction



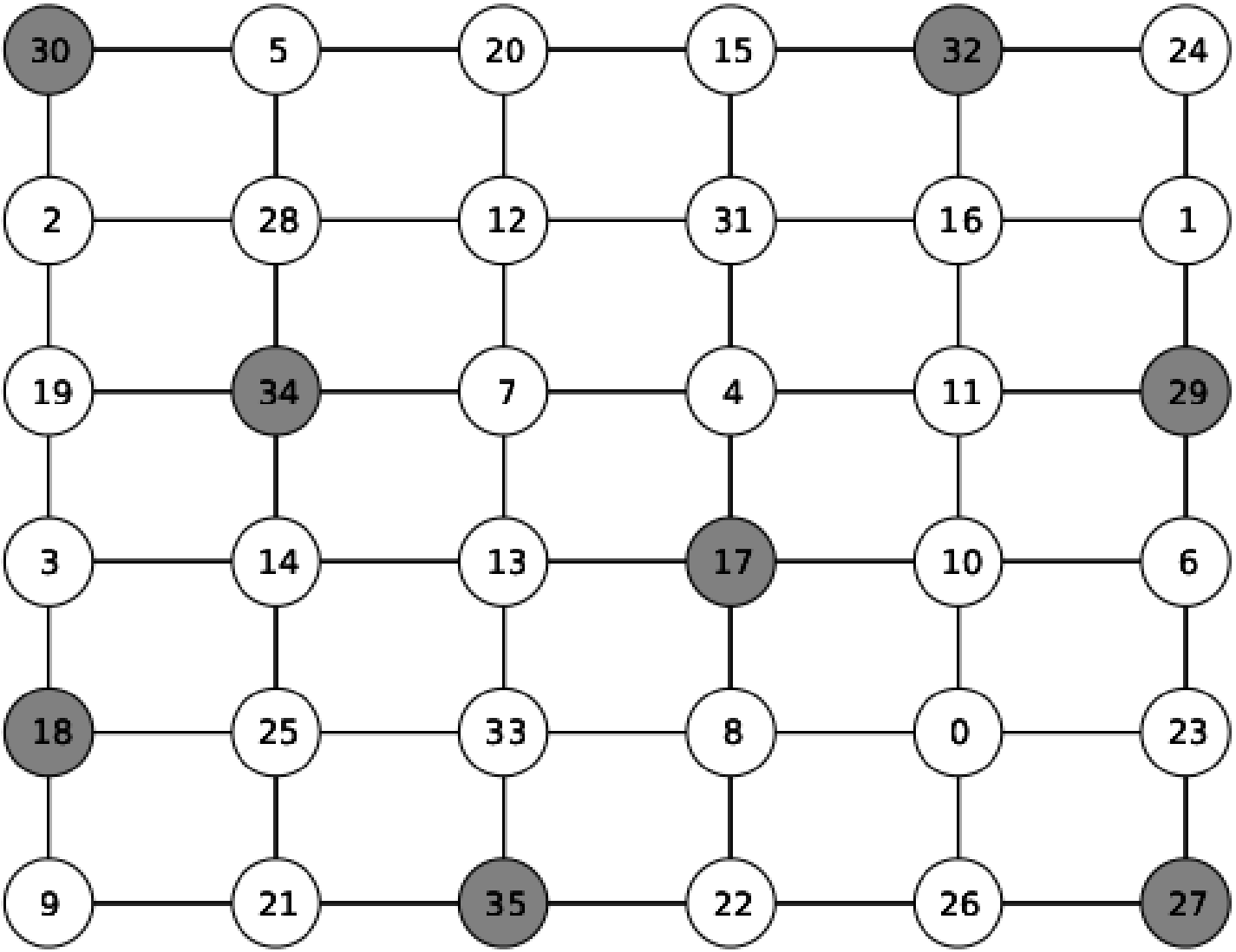
Pick local maxima (or minima) within distance d

MIS-2 Construction



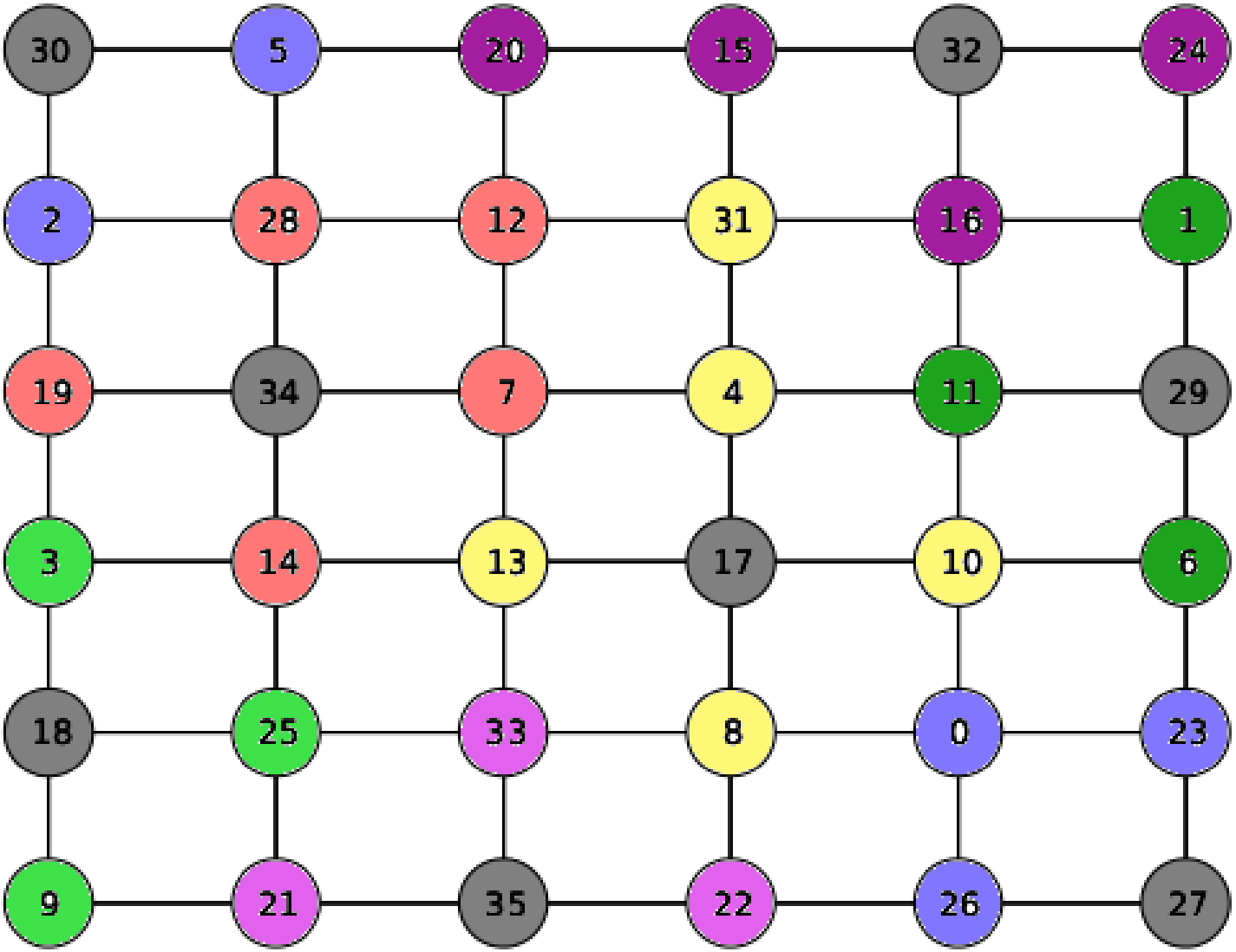
Remove neighbors from candidate list

MIS-2 Construction



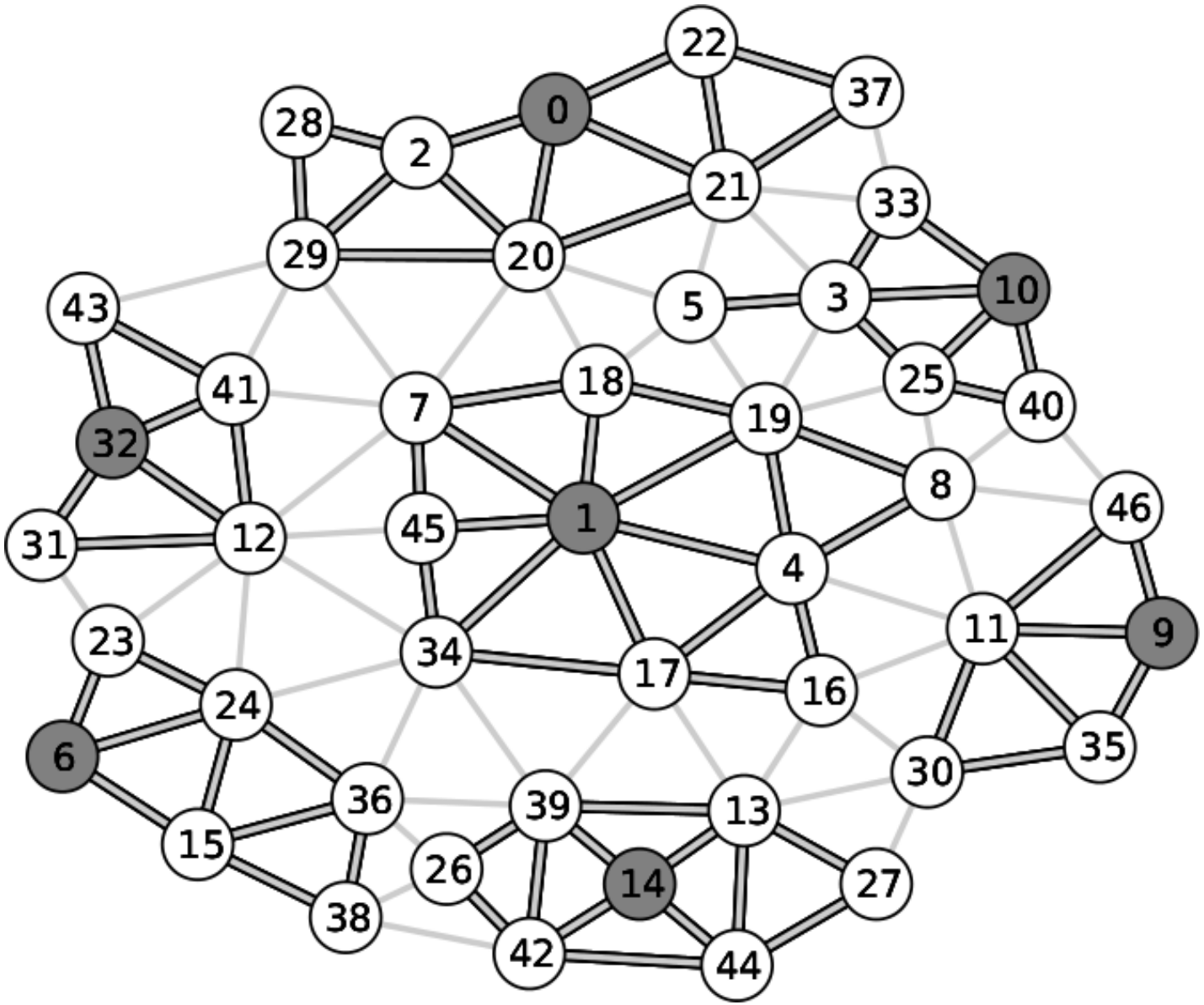
Select remaining MIS nodes

MIS-2 Construction



Add orphans to existing MIS sets

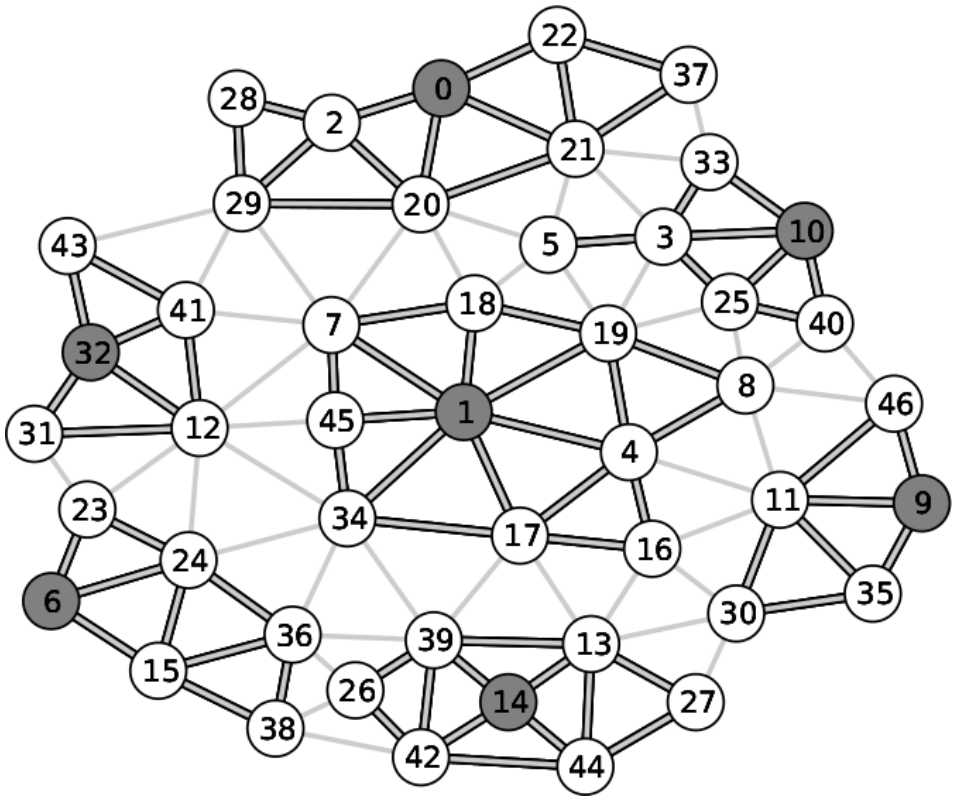
MIS-2 Construction



Maximum Independent Sets (MIS)

Applications

- Algebraic multigrid
- Coloring of a graph
- Graph clustering (BIG DATA!)



Warp Shuffles

Warp Shuffles

A Warp

- (typically) 32 threads in a CUDA thread block execute simultaneously
- they are called a *warp*
- no race conditions within a warp possible
- CUDA variable inside kernel: `warpSize` (compile time constant)

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Problem

- Exchanging data across threads via shared memory is relatively slow

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A Warp

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Problem

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Solution

- Warp shuffle routines:
  - `__shfl_up_sync`
  - `__shfl_down_sync`
  - `__shfl_xor_sync`
  - `__shfl_sync`

Warp Shuffles

```
T __shfl_up_sync(unsigned mask, T var,unsigned int delta);
```

Move thread values to higher thread IDs

- `mask` controls which threads are involved — usually set to `-1` or `0xffffffff`, equivalent to all 1's
- `var` is a local register variable (int, unsigned int, long long, unsigned long long, float or double)
- `delta` is the offset within the warp — current thread value if offset runs out of bounds

Warp Shuffles

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```

Move thread values to higher thread IDs

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- `var` is a local register variable (int, unsigned int, long long, unsigned long long, float or double)
- `delta` is the offset within the warp — current thread value if offset runs out of bounds

```
T __shfl_down_sync(unsigned mask, T var,unsigned int delta);
```

Move thread values to lower thread IDs

Defined similarly

Warp Shuffles

```
T __shfl_xor_sync(unsigned mask, T var,unsigned int laneMask);
```

Move thread values to other XOR'd thread IDs

- an XOR (exclusive or) operation is performed between `laneMask` and the calling thread's `laneID` to determine the lane from which to copy the value
- (`laneMask` constrols the bits to be flipped within `laneID`)
- very useful for reductionoperations and FFTs

Warp Shuffles

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T __shfl_xor_sync(unsigned mask, T var,unsigned int laneMask);
```

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```
T __shfl_sync(unsigned mask, T var,unsigned int srcLane);
```

Get data from a different thread

copies data from the `srcLane` thread

Warp Shuffles

Warning

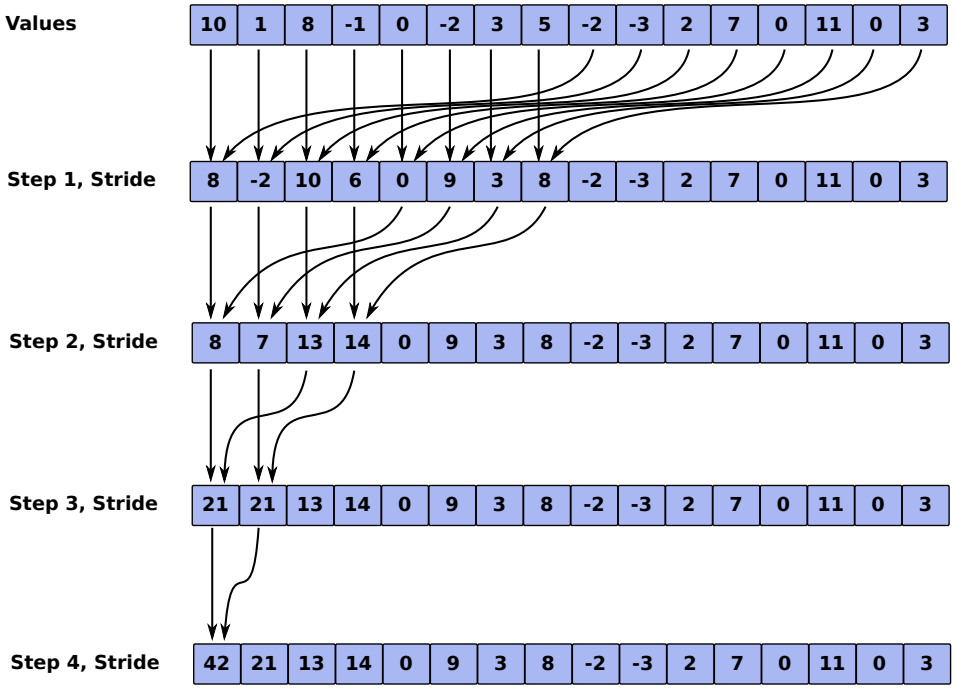
- Threads may only read data from another threadwhich is actively participating in the shuffle command.
- If the target thread is inactive, the retrieved value is undefined.
- Thus, be careful with conditional code!

Reference

- `https://people.maths.ox.ac.uk/gilesm/cuda/lecs/lec4.pdf`

Parallel Primitives

Reductions with Many Threads




```
__kernel my_warp_reduction(double *x) {
double value = x[threadIdx.x];
for (int i=16; i>0; i=i/2)
  value += __shfl_down_sync(-1, value, i);

// thread 0 contains sum of all values within the warp
}
```

Parallel Primitives

Another way to compute warp reductions

```
__kernel my_warp_reduction2(double *x) {
double value = x[threadIdx.x];
for (int i=16; i>0; i=i/2)
  value += __shfl_xor_sync(-1, value, i);

// all threads in the warp contain the warp sum
}
```

Exercises

Environment

- `https://gtx1080.360252.org/2020/ex6/`
- (Might receive visual updates and additional hints over the next days)
- Due: Tuesday, December 1, 2020 at 23:59pm

Hints and Suggestions

- Consider version control for locally developed code
- Please let me know of any bugs or issues