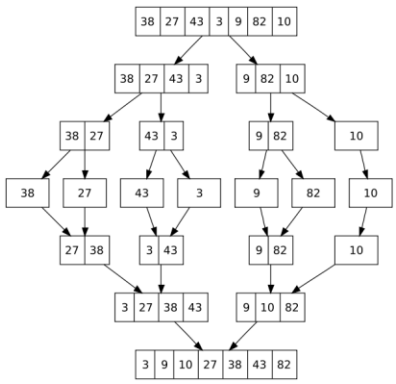
CUDA Misc

Mergesort, Pinned Memory, Device Query, Multi GPU

Parallel Mergesort

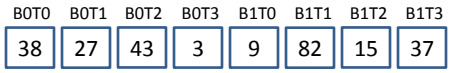
- O(N) runtime with memory copy overhead
  - Not really worth it compared to O(NlgN) sequential version but an interesting exercise
- Regular mergesort



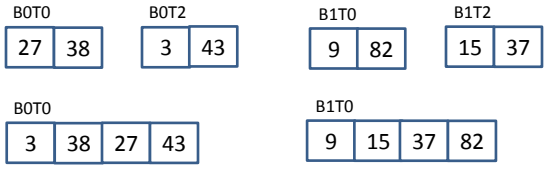
CUDA Mergesort

- Split portion
  - Assign each thread to a number in the unsorted array
  - Example: 2 blocks, 4 threads per block

index = threadIdx.x + (blockIdx.x * blockDim.x)
e.g. index = 3 + (1 * 4) = 7 for Block1 Thread 3



- Merge split into two phases
  - First phase: Sort each block by merging into shared memory



Why can't we keep doing this for the whole array?

Code to sort blocks

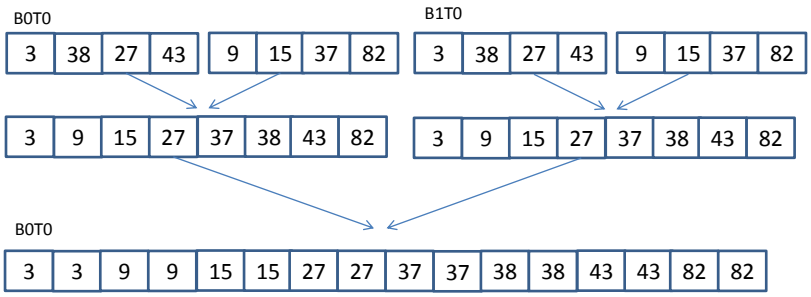
```
// This version only works for N = THREADS*BLOCKS
__global__ void sortBlocks(int *a)
{
    int i=2;
    __shared__ int temp[THREADS];
    while (i <= THREADS)
    {
     if ((threadIdx.x % i)==0)
     {
        int index1 = threadIdx.x + (blockIdx.x * blockDim.x);
        int endIndex1 = index1 + i/2;
        int index2 = endIndex1;
        int endIndex2 = index2 + i/2;
        int targetIndex = threadIdx.x;
        int done = 0;
        while (!done)
        {
            if ((index1 == endIndex1) && (index2 < endIndex2))
                temp[targetIndex++] = a[index2++];
            else if ((index2 == endIndex2) && (index1 < endIndex1))
                temp[targetIndex++] = a[index1++];
            else if (a[index1] < a[index2])
                temp[targetIndex++] = a[index1++];
            else
                temp[targetIndex++] = a[index2++];
            if ((index1==endIndex1) && (index2==endIndex2))
                done = 1;
        }
     }
        __syncthreads();
        a[threadIdx.x + (blockIdx.x*blockDim.x)] = temp[threadIdx.x];
        __syncthreads();
        i *= 2;
    }
}
```

Code for main

```
int main()
{
    int a[N];
    int *dev_a, *dev_temp;

    cudaMalloc((void **) &dev_a, N*sizeof(int));
    cudaMalloc((void **) &dev_temp, N*sizeof(int));

    // Fill array
    srand(time(NULL));
    for (int i = 0; i < N; i++)
    {
        int num = rand() % 100;
        a[i] = num;
        printf("%d ",a[i]);
    }
    printf("\n");

    // Copy data from host to device
    cudaMemcpy(dev_a, a, N*sizeof(int), cudaMemcpyHostToDevice);

    sortBlocks<<<BLOCKS,THREADS>>>(dev_a);
    cudaMemcpy(a, dev_a, N*sizeof(int), cudaMemcpyDeviceToHost);

…
```

Merging Blocks

- We now need to merge the sorted blocks
  - For simplicity, 1 thread per block



Single Step of Parallel Merge

```
__global__ void mergeBlocks(int *a, int *temp, int sortedsize)
{
    int id = blockIdx.x;

    int index1 = id * 2 * sortedsize;
    int endIndex1 = index1 + sortedsize;
    int index2 = endIndex1;
    int endIndex2 = index2 + sortedsize;
    int targetIndex = id * 2 * sortedsize;
    int done = 0;
    while (!done)
    {
        if ((index1 == endIndex1) && (index2 < endIndex2))
            temp[targetIndex++] = a[index2++];
        else if ((index2 == endIndex2) && (index1 < endIndex1))
            temp[targetIndex++] = a[index1++];
        else if (a[index1] < a[index2])
            temp[targetIndex++] = a[index1++];
        else
            temp[targetIndex++] = a[index2++];
        if ((index1==endIndex1) && (index2==endIndex2))
            done = 1;
    }
}
```

temp = device memory same size as a

sortedsize = length of a sorted "block" (doubles in size from original block)

Main code

```
int blocks = BLOCKS/2;
int sortedsize = THREADS;
while (blocks > 0)
{
  mergeBlocks<<<blocks,1>>>(dev_a, dev_temp, sortedsize);
  cudaMemcpy(dev_a, dev_temp, N*sizeof(int), cudaMemcpyDeviceToDevice);
  blocks /= 2;
  sortedsize *= 2;
}
cudaMemcpy(a, dev_a, N*sizeof(int), cudaMemcpyDeviceToHost);
```

Copy from device to device

MergeSort

- With bigger array:

```
#define N 1048576
#define THREADS 512
#define BLOCKS 2048
```

- Our implementation is limited to a power of 2 for the number of blocks and for the number of threads per block
- The slowest part seems to be copying the data back to the host, is there anything we can do about that?

Page-Locked or Pinned Memory

- The CUDA runtime offers `cudaHostAlloc`() which is similar to `malloc`
- `malloc` memory is standard, pageable host memory
- `cudaHostAlloc`() memory is page-locked host memory or pinned memory
  - The OS guarantees it will never page the memory to disk and will reside in physical memory
  - Faster copying to the GPU because paged memory is first copied to pinned memory then DMA copies it to the GPU
- Does take away from total available system memory, may affect system performance

cudaHostAlloc

- Instead of malloc use:

```
int *a;
cudaHostAlloc((void **) &a, size, cudaHostAllocDefault);
…
cudaFreeHost(a);
```

- Won't make much difference on our small mergesort but benchmark test with hundreds of copies:
  - Time using cudaMalloc: 9298.7 ms
  - MB/s during copy up: 2753.1
  - Time using cudaMalloc: 17415.4 ms
  - MB/s during copy down: 1470.0
  - Time using cudaHostAlloc: 6794.8 ms
  - MB/s during copy up: 3767.6
  - Time using cudaHostAlloc: 17167.1 ms
  - MB/s during copy down: 1491.2

Zero-Copy Host Memory

- Skipping, but pinned memory allows the possibility for the GPU to directly access host memory
  - Requires some different flags for cudaHostAlloc
  - Performance win if the GPU is integrated with the host (memory shared with the host anyway)
  - Performance loss for data read multiple times since zero-copy memory is not cached on the GPU

Device Query

- How do you know if you have integrated graphics?
  - Can use deviceQuery to see what devices you have
  - cudaGetDeviceCount(&count)
    - Stores number of CUDA-enabled devices in count
  - cudaGetDeviceProperties(&prop, i)
    - Stores device info into the prop struct for device i

Code

```
#include "stdio.h"

int main()
{
   cudaDeviceProp  prop;

   int count;
   cudaGetDeviceCount(&count);
   for (int i=0; i< count; i++)
   {
      cudaGetDeviceProperties(&prop, i);
      printf( "   --- General Information for device %d ---\n", i );
      printf( "Name:  %s\n", prop.name );
      printf( "Compute capability:  %d.%d\n", prop.major, prop.minor );
      printf( "Clock rate:  %d\n", prop.clockRate );
      printf( "Device copy overlap:  " );
      printf( "Integrated graphics: " );
      if (prop.integrated)
         printf( "True\n" );
      else
         printf( "False\n" );
      if (prop.deviceOverlap)
         printf( "Enabled\n" );
      else
         printf( "Disabled\n");
…
```

Using Multiple GPU's

- Can use cudaSetDevice(deviceNum) but has to run on separate threads
- Fortunately this is not too bad
  - Thread implementation varies by OS
  - Simple example using pthreads
    - Better than fork/exec since threads share the same memory instead of a copy of the memory space

Thread Sample

```
/* Need to compile with -pthread */
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>

typedef struct argdata
{
  int i;
  int return_val;
} arg_data;

void *TaskCode(void *argument)
{
  int tid;
  arg_data *p;

  p = (arg_data *) argument;
  tid = (*p).i;
  printf("Hello World! It's me, thread %d!\n", tid);
  p->return_val = tid;

  return NULL;
}
```

```
int main ()
{
  pthread_t thread1,thread2;
  arg_data arg1, arg2;

  /* create two threads */
  arg1.i = 1;
  arg2.i = 2;
  pthread_create(&thread1, NULL, TaskCode, (void *) &arg1);
  pthread_create(&thread2, NULL, TaskCode, (void *) &arg2);

  /* wait for all threads to complete */
  pthread_join(thread1, NULL);
  pthread_join(thread2, NULL);

   printf("Done, values in return: %d %d\n", arg1.return_val,
                    arg2.return_val);
  return 0;
}
```

Threads with GPU Code

```
// Using two GPU's to increment by 1 an array of 4 integers,
// one GPU to increment the first two, the second GPU to increment the next two
// Don't need to use -pthread with nvcc

#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <assert.h>

typedef struct argdata
{
  int deviceID;
  int *data;
} arg_data;

__global__ void kernel(int *data)
{
  data[threadIdx.x]++;
}

// Use 2 threads to increment 2 integers in an array
void *TaskCode(void *argument)
{
  arg_data *p;
  int *dev_data;

  p = (arg_data *) argument;
  cudaSetDevice(p->deviceID);
  cudaMalloc((void **) &dev_data, 2*sizeof(int));
  cudaMemcpy(dev_data, p->data, 2*sizeof(int), cudaMemcpyHostToDevice);
  kernel<<<1,2>>>(dev_data);
  cudaMemcpy(p->data, dev_data, 2*sizeof(int), cudaMemcpyDeviceToHost);
  cudaFree(dev_data);

  return NULL;
}
```

Main

```
int main ()
{
  pthread_t thread1,thread2;
  arg_data arg1, arg2;
  int a[4];

  a[0] = 0; a[1] = 1; a[2] = 2; a[3] = 3;
  arg1.deviceID = 0;
  arg2.deviceID = 1;
  arg1.data = &a[0];   // Address of first 2 ints
  arg2.data = &a[2];   // Address of second 2 ints

  /* create two threads */
  pthread_create(&thread1, NULL, TaskCode, (void *) &arg1);
  pthread_create(&thread2, NULL, TaskCode, (void *) &arg2);

  /* wait for all threads to complete */
  pthread_join(thread1, NULL);
  pthread_join(thread2, NULL);

  for (int i=0; i < 4; i++)
      printf("%d ", a[i]);
  printf("\n");
  return 0;
}
```