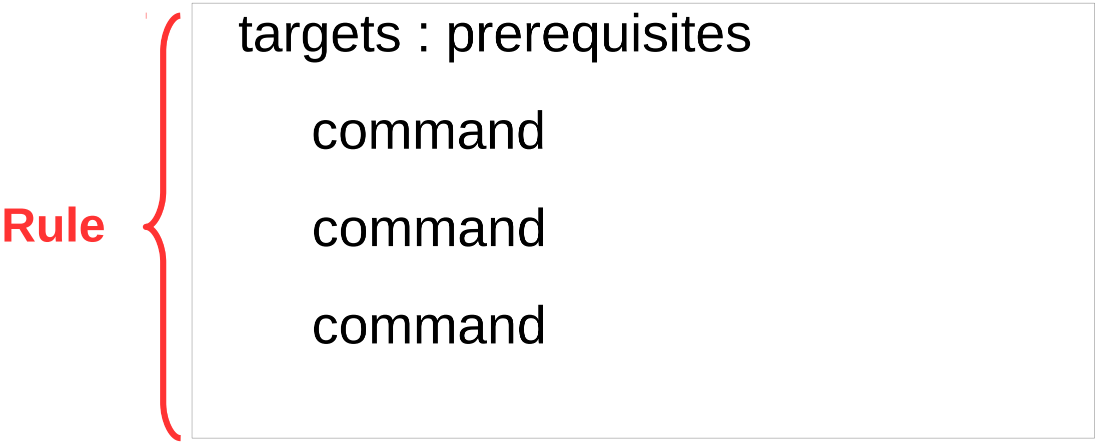
Support: Makefiles, Debugging and Profiling

Makefile

- Makefile is a set of commands
- Makefiles are used when we have dependencies among files
- It is helpful for the large project where there might be many dependencies among the files
- make utility is a command line utility used to process the instructions in the Makefile
- Put the commands in a file called Makefile, and in that directory run the command make

Makefile Syntax



Rule

```
targets : prerequisites
	command
	command
	command
```

- The targets and prerequisites are file names or actions, separated by colon
- The commands are a series of steps
- Note: commands need to start with a tab character, not spaces

Example

```
Hello:
	echo "hello world"
```

```
$ make
echo "hello world"
hello world
```

Running CUDA Program

```
#include <stdio.h>
#include <cuda.h>
__global__ void dkernel() {
    printf(“Hello World.\n”);
}
int main() {
    dkernel<<<1, 32>>>();
    cudaDeviceSynchronize();
    return 0;
}
```

```
clean : blah
    rm  hello
blah : hello
    ./hello
hello :
    nvcc  hello.cu -o hello
```

```
$ make
Hello World.
Hello World.
...
```

32 times

Variables

→ Variables can only be strings

→ Typically you can use := for assignment

→ Reference variables using either ${} or $()

```
file1 := hello

file2 := blah

file3 := clean

${file3} :  $(file2)

    rm  hello

${file2} : $(file1)

    ./hello

$(file1) :

    nvcc  hello.cu -o hello
```

```
$ make
Hello World.
Hello World.
...
```

All target

→ We can use all target for making multiple targets and run them all.

```
all: H1 H2 H3
H1:
    nvcc  hello1.cu -o hello1
    ./hello1
H2:
    nvcc  hello2.cu -o hello2
    ./hello2
H3:
    nvcc  hello3.cu -o hello3
    ./hello3
clean:
    rm -f hello1 hello2 hello3
```

Multiple target

→ When there are multiple targets for a rule, the commands will be run for each target

```
all: call1 call2 call3

call1 call2 call3:

    nvcc  algo1.cu -o algo1

    ./algo1

    nvcc  algo2.cu -o algo2

    ./algo2

clean:

    rm -f algo1 algo2
```

Conditions in Makefiles

```
foo = somestring

all:

ifneq ($(foo), ok)

    echo "foo not equals ok"

else

    echo "nope"

endif
```

```
TARGET_CPU_IS_X86 := 1

all:

ifeq ( $(TARGET_CPU), x86 )

    TARGET_CPU_IS_X86 := 1

else ifeq( $(TARGET_CPU), x86_64 )

    TARGET_CPU_IS_X86 := 1

else

    TARGET_CPU_IS_X86 := 0

endif
```

Loops in Makefiles

```
all:
    nvcc algo.cu -o algo
    for number in 32 100 900 ; do \
        ./algo $$number ; \
    done
```

```
all:
    nvcc algo.cu -o algo
    number=100 ; while [[ $$number -le 1000 ]] ; do \
        ./algo $$number ; \
        ((number = number + 100)) ; \
    done
```

Example

```
all : vertex-removal
      unzip examples/test_cases/Bench.zip;        mv examples/test_cases/*.txt ./ ;
      number=1 ;
      while [[ $$number -le 10 ]] ; do \
                ./vertex-removal t$$number.mtx > vr_graph_$$number.txt ; \
                   ifeq ( $$number , 4 )
                                ((number = number + 2)) ;\
                   else
                                ((number = number + 1)) ;\
                  endif
     done
clean : all
      rm  t*.mtx; rm vertex-removal;
vertex-removal:
      nvcc -std=c++11 -o vertex-removal vertex-removal.cu;
```

Debugging

- Debugging parallel programs is difficult.
  - Non-determinism due to thread-scheduling
  - Output can be different
  - Correct intermediate values may be large
- cuda-gdb
  - for debugging CUDA programs on real hardware
  - Extension to gdb
  - Allows breakpoints, single-step, read/write memory contents.

Sample Error

```
#include <cuda.h>
#include <stdio.h>

__global__ void K(int *x) {
        *x = 0;
}
int main() {
        int *x;
        K<<<2, 10>>>(x);
        cudaDeviceSynchronize();

        return 0;
}
```

Sample Error

```
#include <cuda.h>
#include <stdio.h>

__global__ void K(int *x) {
        *x = 0;
        printf(“%d\n”, *x);      // does not print anything.
}
int main() {
        int *x;
        K<<<2, 10>>>(x);
        cudaDeviceSynchronize();

        return 0;
}
```

Sample Error

```
#include <cuda.h>
#include <stdio.h>

__global__ void K(int *x) {
        *x = 0;
        printf(“%d\n”, *x);
}
int main() {
        int *x;
        K<<<2, 10>>>(x);
        cudaDeviceSynchronize();
        cudaError_t err = cudaGetLastError();
        printf("error=%d, %s, %s\n", err, cudaGetErrorName(err),
                                                         cudaGetErrorString(err));
        return 0;
}
```

error=77, *cudaErrorIllegalAddress*,
an illegal memory access was encountered

CUDA Errors

cudaSuccess	= 0,	/// No errors
cudaErrorMissingConfiguration	= 1,	/// Missing configuration error
cudaErrorMemoryAllocation	= 2,	/// Memory allocation error
cudaErrorInitializationError	= 3,	/// Initialization error
cudaErrorLaunchFailure	= 4,	/// Launch failure
cudaErrorPriorLaunchFailure	= 5,	/// Prior launch failure
cudaErrorLaunchTimeout	= 6,	/// Launch timeout error
cudaErrorLaunchOutOfResources	= 7,	/// Launch out of resources
cudaErrorInvalidDeviceFunction	= 8,	/// Invalid device function
cudaErrorInvalidConfiguration	= 9,	/// Invalid configuration
cudaErrorInvalidDevice	= 10,	/// Invalid device
...		

Homework: Write programs to invoke these errors.

cuda-gdb

- Generate debug information
  - nvcc -g -G file.cu
  - Disables optimizations.
- Run with cuda-gdb
  - cuda-gdb a.out
  - > run
- Due to lots of threads, cuda-gdb works with a focus (current thread).

```
__global__ void K(int *x)
{
        *x = 0;
        printf(“%d\n”, *x);
}
```

```
(cuda-gdb) run
Starting program: ..../a.out
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib64/libthread_db.so.1".
[New Thread 0x7ffff7396700 (LWP 10305)]
[New Thread 0x7ffff696d700 (LWP 10306)]

CUDA Exception: Device Illegal Address
The exception was triggered in device 0.

Program received signal CUDA_EXCEPTION_10, Device Illegal Address.
[Switching focus to CUDA kernel 0, grid 1, block (1,0,0), thread (0,0,0), device 0, sm 13, warp 0, lane 0]
0x0000000000aa9510 in K<<<(2,1,1),(10,1,1)>>> (x=0x0) at gdb2.cu:6
6               printf("%d\n", *x);
(cuda-gdb)
```

cuda-gdb

```
(cuda-gdb) info cuda kernels
  Kernel Parent Dev Grid Status   SMs Mask GridDim BlockDim Invocation
*      0      -        0     1    Active 0x00006000  (2,1,1)    (10,1,1)   K(x=0x0)
(cuda-gdb) info threads
  Id   Target Id          Frame
  3    Thread 0x7ffff696d700 (LWP 10497) "a.out" 0x00000038db4df113 in poll ()
   from /lib64/libc.so.6
  2    Thread 0x7ffff7396700 (LWP 10496) "a.out" 0x00000038db4eac6f in
accept4
    () from /lib64/libc.so.6
* 1    Thread 0x7ffff7fca720 (LWP 10487) "a.out" 0x00007ffff77a2118 in
cudbgApiDetach () from /usr/lib64/libcuda.so.1
```

cuda-gdb

```
(cuda-gdb) info cuda threads

  BlockIdx ThreadIdx To BlockIdx ThreadIdx Count      Virtual PC Filename  Line

Kernel 0

*  (0,0,0)   (0,0,0)     (1,0,0)   (9,0,0)    20 0x0000000000aa9f50  gdb2.cu     6

(cuda-gdb) cuda kernel block thread

kernel 0, block (0,0,0), thread (0,0,0)

(cuda-gdb) cuda block 1 thread 0

[Switching focus to CUDA kernel 0, grid 1, block (1,0,0), thread (0,0,0), device
0, sm 13, warp 0, lane 0]

0x0000000000aa9510      6               printf("%d\n", *x);

(cuda-gdb) cuda kernel block thread

kernel 0, block (1,0,0), thread (0,0,0)
```

Breakpoints

- break main   // first instruction in main
- break file.cu:223 // file:line
- set cuda break_on_launch application

  // kernel entry breakpoint
- break file.cu:23 if threadIdx.x == 1 && i < 5

  // conditional breakpoint

Step

- Once at a breakpoint, you can single-step
  - step, s or <enter>

```
(cuda-gdb) info cuda sms
  SM  Active Warps Mask
Device 0
   0 0x0000000000000000
   1 0x0000000000000000
   2 0x0000000000000000
   3 0x0000000000000000
   4 0x0000000000000000
   5 0x0000000000000000
   6 0x0000000000000000
   7 0x0000000000000000
   8 0x0000000000000000
   9 0x0000000000000000
  10 0x0000000000000000
  11 0x0000000000000000
  12 0x0000000000000000
  13 0x0000000000000001
* 14 0x0000000000000001
```

```
(cuda-gdb) info cuda warps
  Wp Active Lanes Mask Divergent Lanes Mask Active Physical PC Kernel BlockIdx First Active
ThreadIdx
Device 0 SM 14
*  0       0x000003ff          0x00000000 0x0000000000000110     0  (0,0,0)              (0,0,0)
   1       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   2       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   3       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   4       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   5       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   6       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   7       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   8       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
   9       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
  10       0x00000000          0x00000000                n/a    n/a      n/a                  n/a
---Type <return> to continue, or q <return> to quit---
```

```
(cuda-gdb) info cuda lanes
  Ln   State        Physical PC    ThreadIdx         Exception
Device 0 SM 14 Warp 0
*  0   active  0x0000000000000110   (0,0,0) Device Illegal Address
   1   active  0x0000000000000110   (1,0,0) Device Illegal Address
   2   active  0x0000000000000110   (2,0,0) Device Illegal Address
   3   active  0x0000000000000110   (3,0,0) Device Illegal Address
   4   active  0x0000000000000110   (4,0,0) Device Illegal Address
   5   active  0x0000000000000110   (5,0,0) Device Illegal Address
   6   active  0x0000000000000110   (6,0,0) Device Illegal Address
   7   active  0x0000000000000110   (7,0,0) Device Illegal Address
   8   active  0x0000000000000110   (8,0,0) Device Illegal Address
   9   active  0x0000000000000110   (9,0,0) Device Illegal Address
  10  inactive        n/a            n/a          n/a
  11  inactive        n/a            n/a          n/a
  12  inactive        n/a            n/a          n/a
  ...
  29  inactive        n/a            n/a          n/a
  30  inactive        n/a            n/a          n/a
  31  inactive        n/a            n/a          n/a
```

Homework

For the given program, what sequence of cuda-gdb commands would you use to identify the error?

```
__global__ void K(int *p) {
        *p = 0;
        printf("%d\n", *p);
}
int main() {
        int *x, *y;
        cudaMalloc(&x, sizeof(int));
        K<<<2, 10>>>(x);
        cudaDeviceSynchronize();
        y = x;
        cudaFree(y);
        K<<<2, 10>>>(x);
        cudaDeviceSynchronize();
        return 0;
}
```

Profiling

- Measuring “indicators” of performance
  - Time taken by various kernels
  - Memory utilization
  - Number of cache misses
  - Degree of divergence
  - Degree of coalescing
  - …
- Intrusive versus non-intrusive

CUDA Profiler

- nvprof: command-line
- nvvp, nsight: Visual Profilers

nvprof

- No changes required to the binary. Uses defaults.
  - nvprof a.out
- To profile part of a program, use *cudaProfilerStart()* and *Stop()*.
  - Include *cuda_profiler_api.h*
  - nvprof --profile-from-start off a.out

```
__global__ void K1(int num) {
        num += num;
        ++num;
}
__device__ int sum = 0;
__global__ void K2(int num) {
        atomicAdd(&sum, num);
}
__global__ void K3(int num) {
        __shared__ int sum;
        sum = 0;
        __syncthreads();
        sum += num;
}
int main() {
        for (unsigned ii = 0; ii < 100; ++ii) {
                K1<<<5, 32>>>(ii);          cudaDeviceSynchronize();
        }
        for (unsigned ii = 0; ii < 100; ++ii) {
                K2<<<5, 32>>>(ii);          cudaDeviceSynchronize();
        }
        for (unsigned ii = 0; ii < 100; ++ii) {
                K3<<<5, 32>>>(ii);          cudaDeviceSynchronize();
        }
        return 0;
}
```

Which kernel should you optimize?
(Which kernel consumes more time?)

```
$ nvprof  a.out

==26519== NVPROF is profiling process 26519, command: a.out
==26519== Profiling application: a.out
==26519== Profiling result:
Time(%)      Time     Calls       Avg       Min       Max  Name
 39.46%  191.46us       100  1.9140us  1.8880us  2.1440us  K2(int)
 33.86%  164.26us       100  1.6420us  1.6000us  1.8880us  K3(int)
 26.68%  129.44us       100  1.2940us  1.2480us  1.5360us  K1(int)


==26519== API calls:
Time(%)      Time     Calls       Avg       Min       Max  Name
 95.75%  369.08ms       300  1.2303ms  10.560us  364.03ms  cudaLaunch
  2.33%  8.9986ms       728  12.360us     186ns  619.78us  cuDeviceGetAttribute
  0.91%  3.5039ms         8  437.98us  396.85us  450.61us  cuDeviceTotalMem
  0.73%  2.8134ms       300  9.3780us  6.4650us  32.547us  cudaDeviceSynchronize
  0.18%  699.99us         8  87.498us  85.431us  90.737us  cuDeviceGetName
  0.05%  194.20us       300     647ns     339ns  10.694us  cudaConfigureCall
  0.04%  156.27us       300     520ns     292ns  2.2700us  cudaSetupArgument
  0.00%  9.4130us        24     392ns     186ns     862ns  cuDeviceGet
  0.00%  5.7760us         3  1.9250us     317ns  4.7490us  cuDeviceGetCount
```

nvprof

- Supports device-specific profiling
- Supports remote profiling
- Output can be dumped to files as a .csv
- ...