High Performance GPGPU programming with OCaml

OCaml 2013

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September 24, 2013

Outline

GPGPU?

Classic Dedicated GPU Hardware

- Several Multiprocessors
- Dedicated Memory
- Connected to a host through a PCI-Express slot
- Data are transferred between the GPU and the Host using DMA

Current Hardware

	CPU	GPU
# cores	4–16	300–2000
Max Memory	32GB	6GB
GFLOPS SP	200	1000–4000
GFLOPS DP	100	100–1000

Vector Addition

```
__kernel void vec_add(__global const double * c, __global const double * a, ↩
    __global double * b, int N)
{
    int nIndex = get_global_id(0);
    if (nIndex >= N)
        return;
    c[nIndex] = a[nIndex] + b[nIndex];
}
```

GPGPU Programming In Practice

A Small Example : GPGPU Host Program in C

```c
// create OpenCL device & context
cl_context hContext;
hContext = clCreateContextFromType(0, ↩
      CL_DEVICE_TYPE_GPU,
                              0, 0, 0);
// query all devices available to the context
size_t nContextDescriptorSize;
clGetContextInfo(hContext, CL_CONTEXT_DEVICES,
                 0, 0, &nContextDescriptorSize);
cl_device_id * aDevices = malloc(↩
      nContextDescriptorSize);
clGetContextInfo(hContext, CL_CONTEXT_DEVICES,
                 nContextDescriptorSize, aDevices, 0)↩
                           ;
// create a command queue for first device the ↩
      context reported
cl_command_queue hCmdQueue;
hCmdQueue = clCreateCommandQueue(hContext, aDevices↩
      [0], 0, 0);
// create & compile program
cl_program hProgram;
hProgram = clCreateProgramWithSource(hContext, 1,
                                     sProgramSource, ↩
                                            0, 0);
clBuildProgram(hProgram, 0, 0, 0, 0, 0);

// create kernel
cl_kernel hKernel;
hKernel = clCreateKernel(hProgram, “”vec_add, 0);

// allocate device memory
cl_mem hDeviceMemA, hDeviceMemB, hDeviceMemC;
hDeviceMemA = clCreateBuffer(hContext,
                 CL_MEM_READ_ONLY | ↩
                       CL_MEM_COPY_HOST_PTR,
                 cnDimension * sizeof(cl_double),
                 pA,
                 0);
hDeviceMemB = clCreateBuffer(hContext,
                 CL_MEM_READ_ONLY | ↩
                       CL_MEM_COPY_HOST_PTR,
                 cnDimension * sizeof(cl_double),
                 pA,
                 0);
hDeviceMemC = clCreateBuffer(hContext,
                 CL_MEM_WRITE_ONLY,
                 cnDimension * sizeof(cl_double),
                 0, 0);
// setup parameter values
clSetKernelArg(hKernel, 0, sizeof(cl_mem), (void *)&↩
      hDeviceMemA);
clSetKernelArg(hKernel, 1, sizeof(cl_mem), (void *)&↩
      hDeviceMemB);
clSetKernelArg(hKernel, 2, sizeof(cl_mem), (void *)&↩
      hDeviceMemC);
// execute kernel
clEnqueueNDRangeKernel(hCmdQueue, hKernel, 1, 0,
                       &cnDimension, 0, 0, 0, 0);
// copy results from device back to host
clEnqueueReadBuffer(hContext, hDeviceMemC, CL_TRUE, ↩
      0,
                    cnDimension * sizeof(cl_double),
                    pC, 0, 0, 0);
clReleaseMemObj(hDeviceMemA);
clReleaseMemObj(hDeviceMemB);
clReleaseMemObj(hDeviceMemC);
```

Motivations

OCaml and GPGPU complement each other

GPGPU frameworks are

- Highly Parallel
- Architecture Sensitive
- Very Low-Level

OCaml is

- Mainly Sequential
- Multi-platform/architecture
- Very High-Level

Idea

- Allow OCaml developers to use GPGPU with their favorite language.
- Use OCaml to develop high level abstractions for GPGPU.
- Make GPGPU programming safer and easier

Host Side Solution

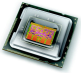
Stream Processing with OCaml

spoc
stream processing
with OCaml

Features

- Allow use of Cuda/OpenCL frameworks with OCaml
- Unify these two frameworks
- Abstract memory transfers

A Little Example



CPU RAM

GPU0 RAM

GPU1 RAM

Example

```
let dev = Devices.init ()
let n = 1_000_000
let v1 = Vector.create Vector.float64 n
let v2 = Vector.create Vector.float64 n
let v3 = Vector.create Vector.float64 n

let k = vector_add (v1, v2, v3, n)
let block = {blockX = 1024; blockY = 1; blockZ = 1}
let grid={gridX=(n+1024-1)/1024; gridY=1; gridZ=1}

let main () =
  random_fill v1;
  random_fill v2;
  Kernel.run k (block,grid) dev.(0);
  for i = 0 to Vector.length v3 - 1 do
   Printf.printf "res[%d] = %f; " i v3.[<i>]
  done;
```

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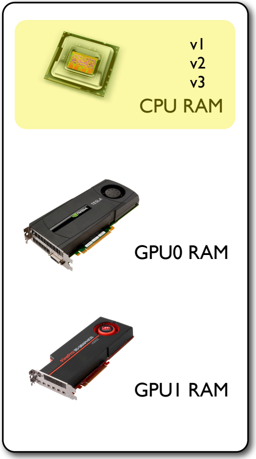

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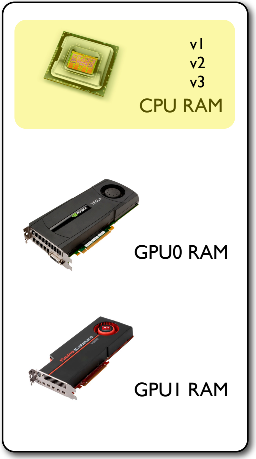

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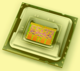

v1
v2
v3
CPU RAM

GPU0 RAM

GPU1 RAM

Example

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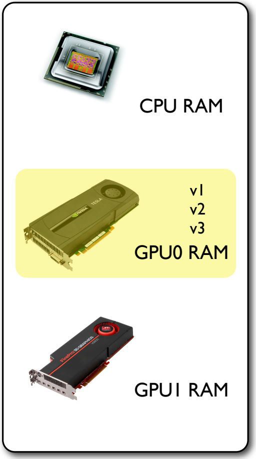

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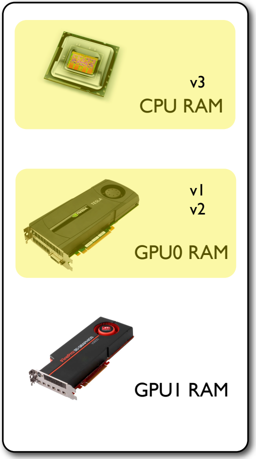
A Little Example



Example

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let main () =
  random_fill v1;
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  Kernel.run k (block,grid) dev.(0);
  for i = 0 to Vector.length v3 - 1 do
   Printf.printf "res[%d] = %f; " i v3.[<i>]
  done;
```

How to express kernels

What we want

- Simple to express
- Predictable performance
- Easily extensible
- Current high performance libraries
- Optimisable
- Safer

Two Solutions

Interoperability with Cuda/OpenCL kernels

- Higher optimisations
- Compatible with current libraries
- Less safe

A DSL for OCaml : Sarek

- Easy to express
- Easy transformation from OCaml
- Safer

Sarek : Stream ARchitecture using Extensible Kernels

Sarek Vector Addition

```
let vec_add = kern a b c n ->
  let open Std in
  let idx = global_thread_id in
  if idx < n then
    c.[<idx>] <- a.[<idx>] + b.[<idx>]
```

OpenCL Vector Addition

```
__kernel void vec_add(__global const double * c, __global const double * a, ↩
     __global double * b, int N)
{
    int nIndex = get_global_id(0);
    if (nIndex >= N)
          return;
    c[nIndex] = a[nIndex] + b[nIndex];
}
```

Sarek

Sarek Vector Addition

```
let vec_add = kern a b c n ->
  let open Std in
  let idx = global_thread_id in
  if idx < n then
    c.[<idx>] <- a.[<idx>] + b.[<idx>]
```

Sarek features

- Monomorphic
- Imperative
- Specific GPGPU globals
- Portable
- Toplevel compatible
- ML-like syntax
- Type inference
- Static type checking
- Static compilation to OCaml code
- Dynamic compilation to Cuda and OpenCL

Vector Addition

SPOC + Sarek

```
open Spoc
let vec_add = kern a b c n ->
  let open Std in
  let idx = global_thread_id in
  if idx < n then
    c.[<idx>] <- a.[<idx>] + b.[<idx>]

let dev = Devices.init ()
let n = 1_000_000
let v1 = Vector.create Vector.float64 n
let v2 = Vector.create Vector.float64 n
let v3 = Vector.create Vector.float64 n

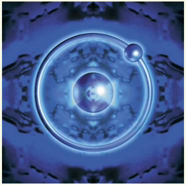
let block = {blockX = 1024; blockY = 1; blockZ = 1}
let grid={gridX=(n+1024-1)/1024; gridY=1; gridZ=1}

let main () =
  random_fill v1;
  random_fill v2;
  Kirc.gen vec_add;
  Kirc.run vec_add  (v1, v2, v3, n) (block,grid) dev.(0);
  for i = 0 to Vector.length v3 - 1 do
   Printf.printf "res[%d] = %f; " i v3.[<i>]
  done;
```

Real-world Example

PROP

- Included in the 2DRMP[a][b] suite
- Simulates e^- scattering in H-like ions at intermediates energies
- PROP Propagates a $\mathcal{R}$-matrix in a two-electrons space
- Computations mainly implies matrix multiplications
- Computed matrices grow during computation
- Programmed in Fortran
- Compatible with sequential architectures, HPC clusters, super-computers



[a] NS Scott, MP Scott, PG Burke, T. Stitt, V. Faro-Maza, C. Denis, and A. Maniopoulou. 2DRMP : A suite of two- dimensional R-matrix propagation codes. Computer Physics Communications, 2009

[b] HPC prize for Machine Utilization, awarded by the UK Research Councils' HEC Strategy Committee, 2006

Results: PROP

Running Device	Running Time	Speedup / Fortran
Fortran CPU 1 core	4271.00s (71m11s)	1.00
Fortran CPU 4 core	2178.00s (36m18s)	1.96
Fortran GPU	951.00s (15m51s)	4.49
OCaml GPU	1018.00s **(16m58s)**	4.20
OCaml (+ Sarek) GPU	1195.00s **(19m55s)**	3.57

SPOC+Sarek achieves 80% of hand-tuned Fortran performance.
SPOC+external kernels is on par with Fortran (93%)

Type-safe — 30% code reduction
Memory manager + GC — No more transfers

Ready for the real world...

Conclusion

SPOC : Stream Processing with OCaml

- OCaml library
- Unifies Cuda/OpenCL
- Offers automatic transfers
- Is compatible with current high performance libraries

Sarek : Stream ARchitecture using Extensible Kernels

- OCaml-like syntax
- Type inference
- Easily extensible via OCaml code

Conclusion

Results

- Great performance
- Portability for free
- Great for both GPU and multicore CPU
- Nice playground for further abstractions

Who can benefit from it?

- OCaml programmers → better performance
- HPC programmers → simpler and safer than usual low-level tools
- Parallel libraries developers → efficient, portable, extensible
- Education - Industry - Research

Current and Future Work

Sarek

- Custom types, Function declarations, Recursion, Exceptions, ...
- Buid parallel skeletons using SPOC and Sarek

Example

```
let v1 = Vector.create Vector.float64 10_000
and v2 = Vector.create Vector.float64 10_000
in
let vec3 = map2 (kern a b -> a + b) vec1 vec2
```

Thanks

Emmanuel Chailloux
Jean-Luc Lamotte

open-source distribution : http://www.algo-prog.info/spoc/
Or install it via OPAM, the OCaml Package Manager
SPOC is compatible with x86_64: Unix (Linux, Mac OS X), Windows

For more information
mathias.bourgoin@lip6.fr

Using SPOC with Multicore CPUs?

Why?

OCaml cannot run parallel threads...
Multiple “solutions” have been considered :

- New runtime/GC $\Rightarrow$ OC4MC experiment ?
- Automatic forking $\Rightarrow$ ParMap?
- Extension for distributed computing $\Rightarrow$ JoCaml?
- Probably many other solutions (new compiler?, parallel virtual machine?, etc)

Benchmarks using SPOC on Multicore CPUs

Comparison

- **ParMap** : data parallel, very similar to current OCaml map/fold
- **OC4MC** : Posix threads, compatible with current OCaml code
- **SPOC** : GPGPU kernels on CPU, mainly data parallel, needs OpenCL

Benchmarks

	OCaml	ParMap	OC4MC	SPOC + Sarek
Power	11s14	3s30	-	<1s
Matmul	85s	-	28s	6.2s

Running on a quad-core Intel Core-i7 3770@3.5GHz