The Offload C++ Programming System

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Codeplay background

- Compiler company based in Edinburgh, Scotland

Codeplay's office in central Edinburgh

- 8 years experience in C/C++ and shader compilers
- Target special-purpose parallel hardware architectures
  - PlayStation®2
  - Ageia PhysX
  - Cell BE, PlayStation®3
  - Multi-core processors
  - x86: SSE, MMX, 3DNow!

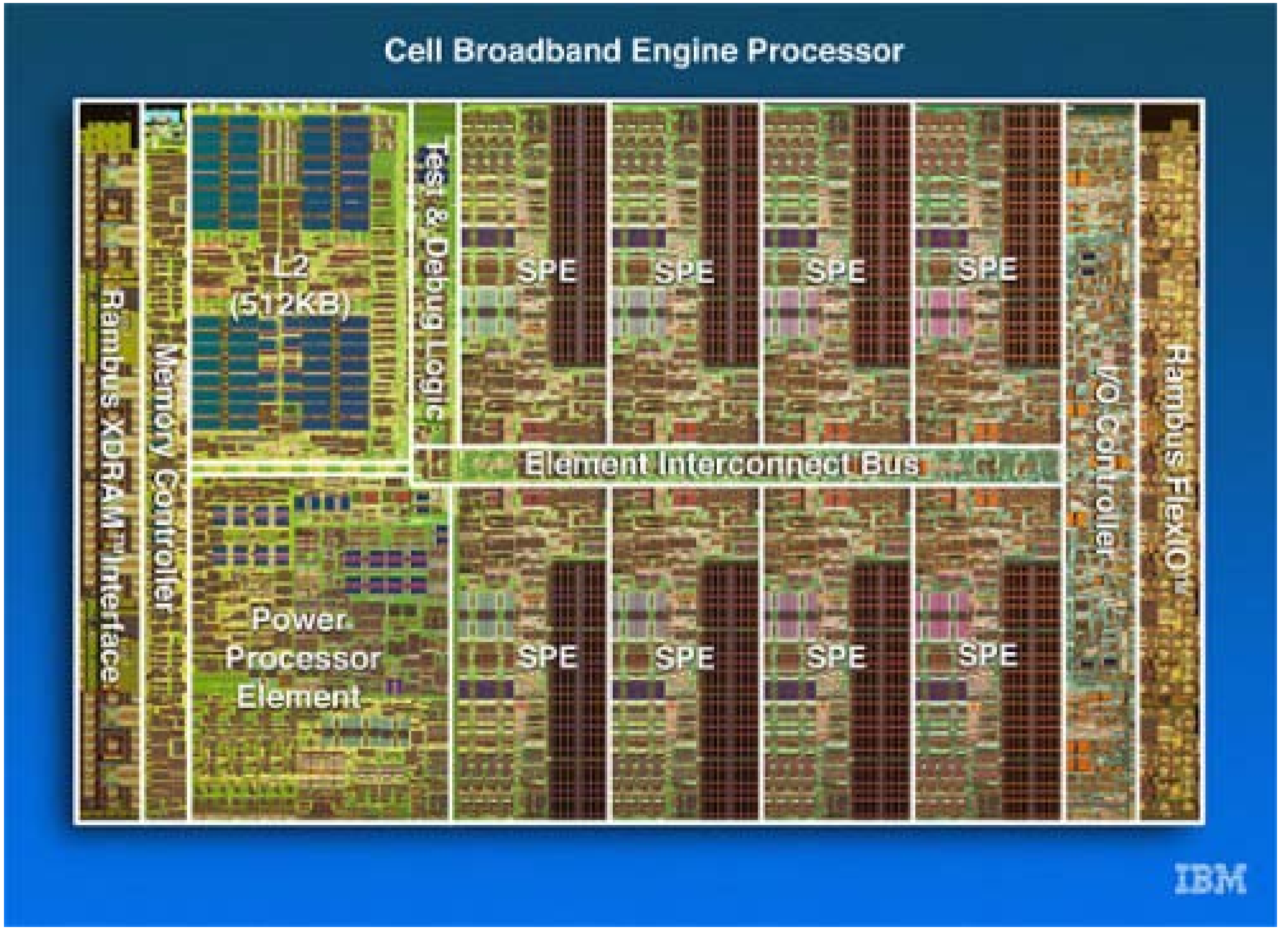
Cellfactor game from Ageia

- Have developed technology to simplify application deployment on complex & evolving parallel systems

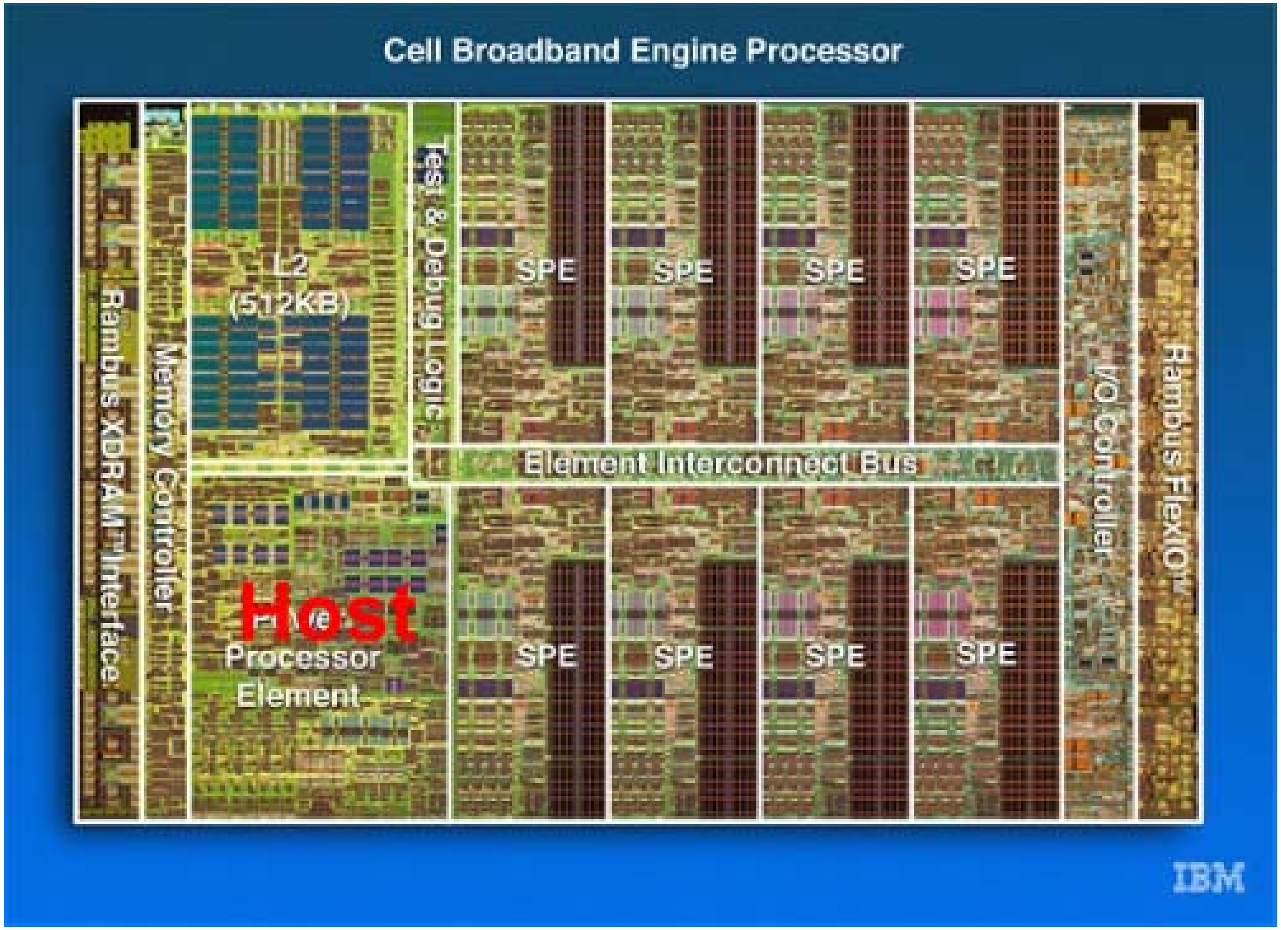
Outline

- Challenge of programming for ‘host and accelerators’
- Offload C++
- Automatic Call Graph Duplication
- Methodology for Offloading C++
- Conclusion & Questions

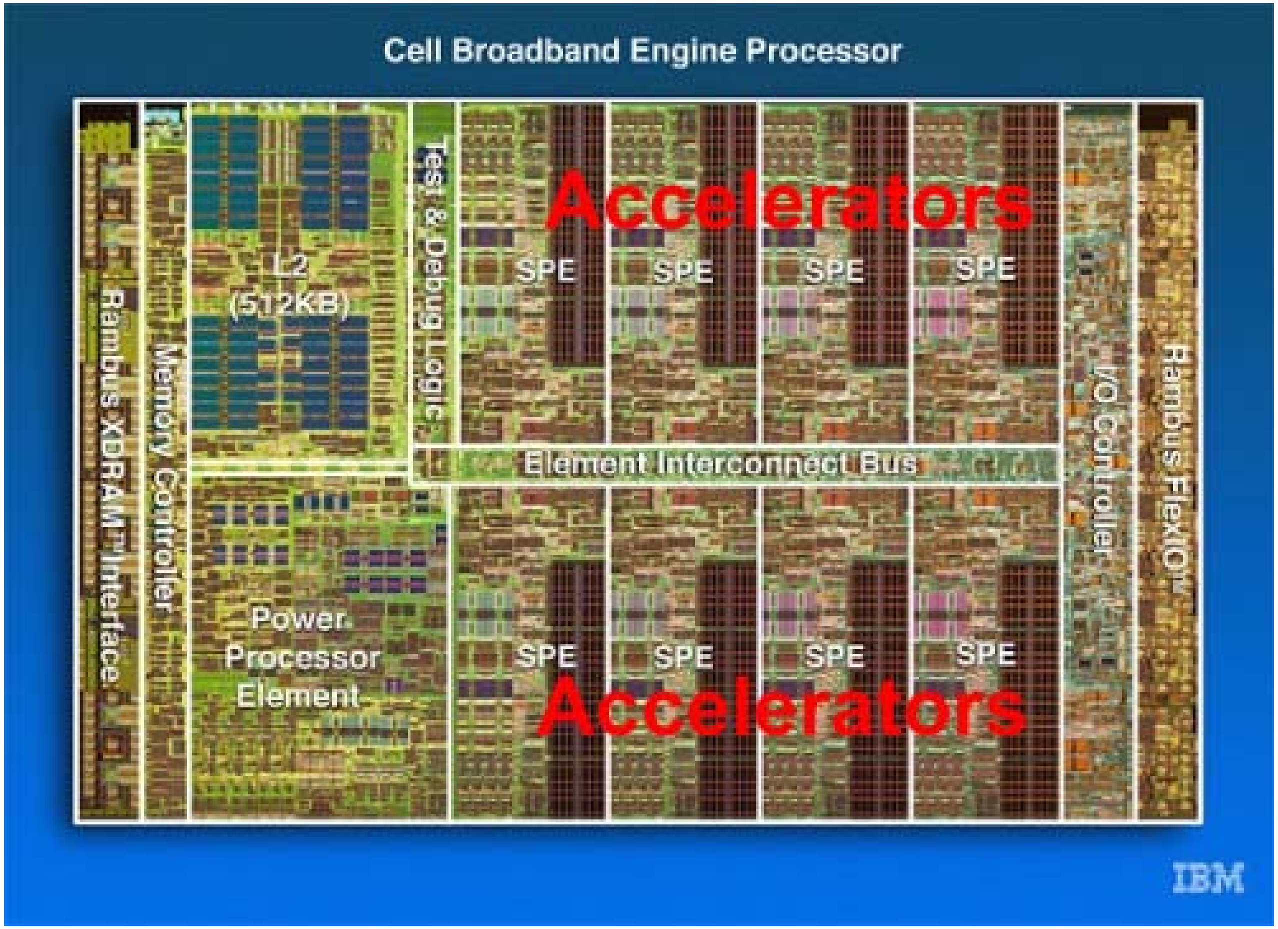
‘Host and Accelerators’



‘Host and Accelerators’



‘Host and Accelerators’



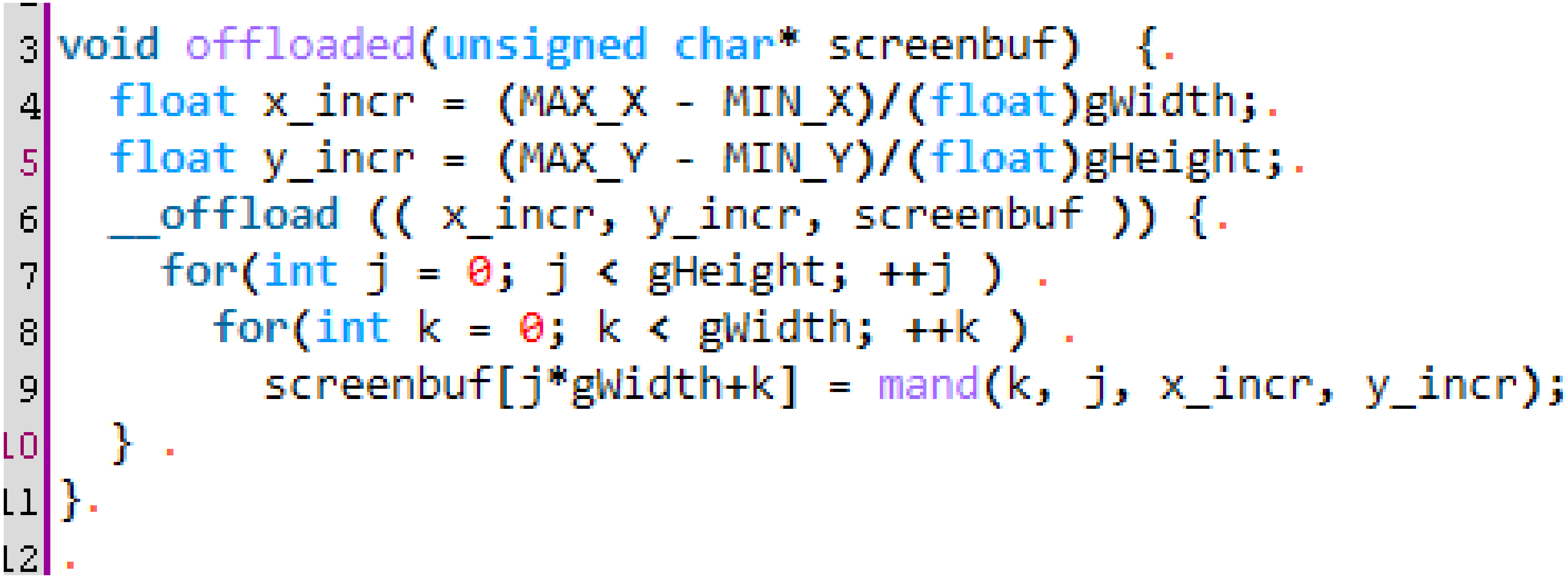
Porting Software to Multi-core

- Challenges
  - Maintain portability, limit scope of change
  - Hardware limitations
  - Scope for error: less static checking
  - Explicit management of data transfers
  - Time consuming
- Hard to adapt existing concurrent software

Offload C++

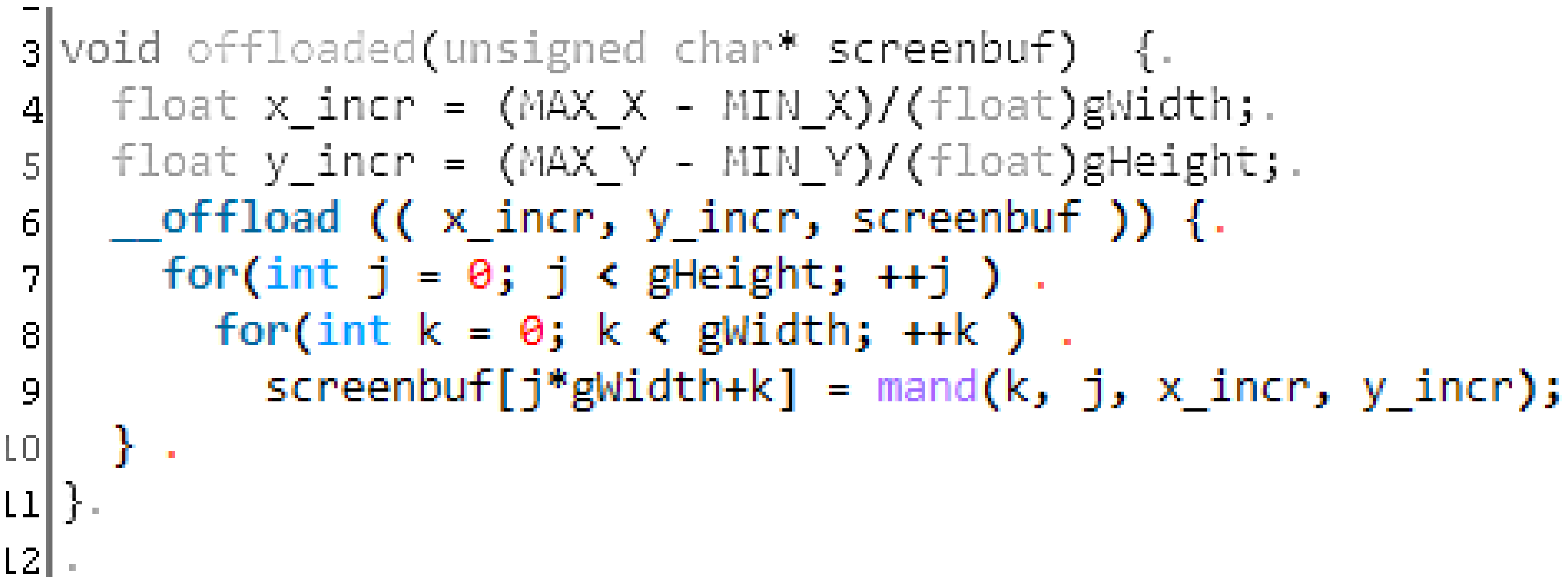
- Conservative C++ extension
  - Applicable to *existing* code bases
  - Can #define extensions out of code
- Targets heterogeneous cores
  - Host core + accelerator cores
  - Distinct memory spaces
- Programming model
  - Migrate a host thread onto an accelerator

Offload Blocks



```
void offloaded(unsigned char* screenbuf)  {
  float x_incr = (MAX_X - MIN_X)/(float)gWidth;
  float y_incr = (MAX_Y - MIN_Y)/(float)gHeight;
  __offload (( x_incr, y_incr, screenbuf )) {
    for(int j = 0; j < gHeight; ++j )
      for(int k = 0; k < gWidth; ++k )
        screenbuf[j*gWidth+k] = mand(k, j, x_incr, y_incr);
  }
}
```

Offload Blocks



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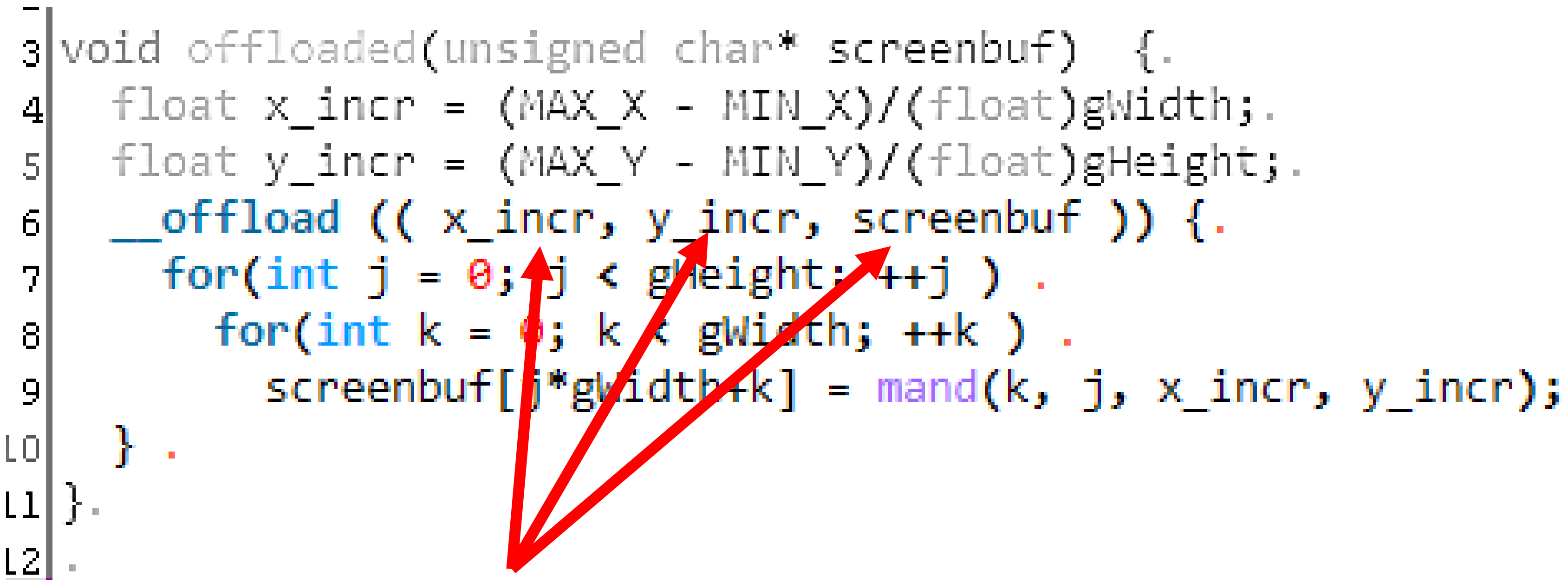

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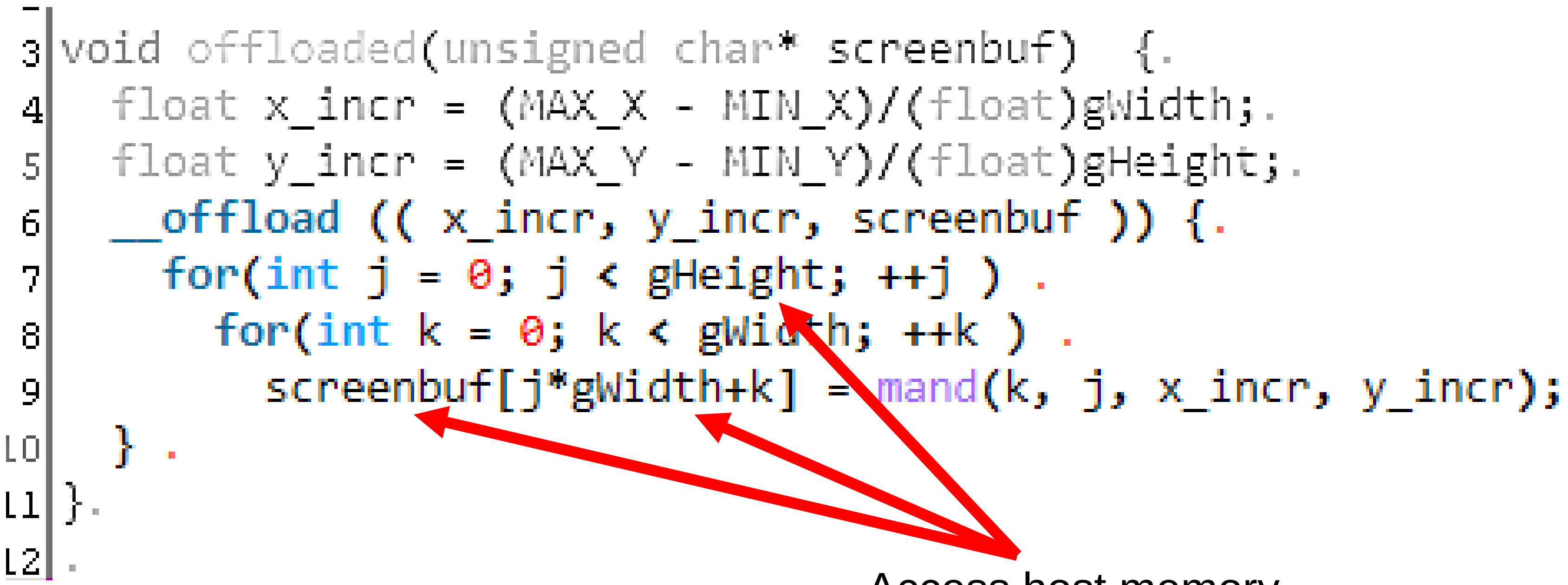
Parameters

Offload Blocks



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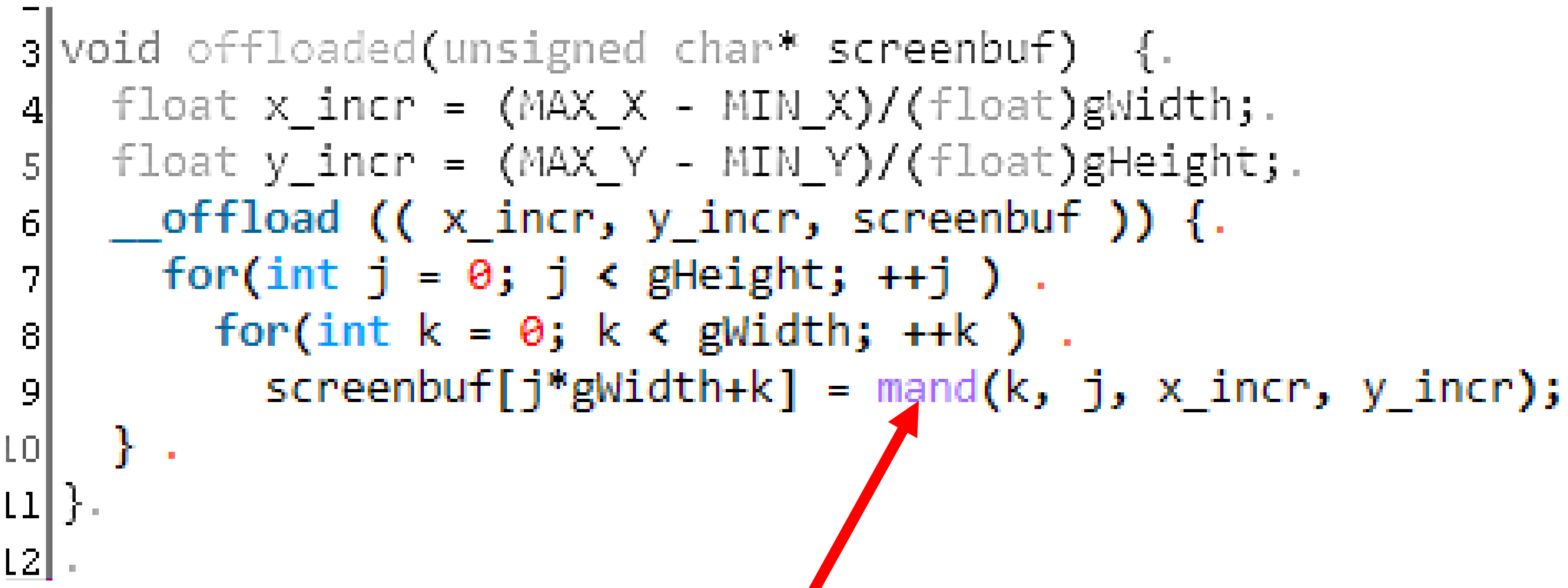
  }
}
```

Access host memory

Offload Blocks



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  float y_incr = (MAX_Y - MIN_Y)/(float)gHeight;
  __offload (( x_incr, y_incr, screenbuf )) {
    for(int j = 0; j < gHeight; ++j )
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        screenbuf[j*gWidth+k] = mand(k, j, x_incr, y_incr);
  }
}
```

Call graph duplication

Automatic Call Graph Duplication

- Compiles for host and accelerator
- Adapts code to handle distinct memory spaces
  - Produces ‘offload’ duplicates to run on accelerator
- Automation
  - Time saving / Enable experimentation
  - Increase the amount of code offloaded
  - Reduce scope of modifications to program code
  - Keep a single version of program source code

Multiple Memory Spaces in C++

- C++ assumes a single memory space
- Not true for ‘hosts and accelerators’
  - May have a multi-level memory hierarchy
- Introduces scope for programmer error
  - Confusion of pointers to different memory spaces
- Interacts badly with C++
  - function pointers / vtables

Offload C++ and Pointers

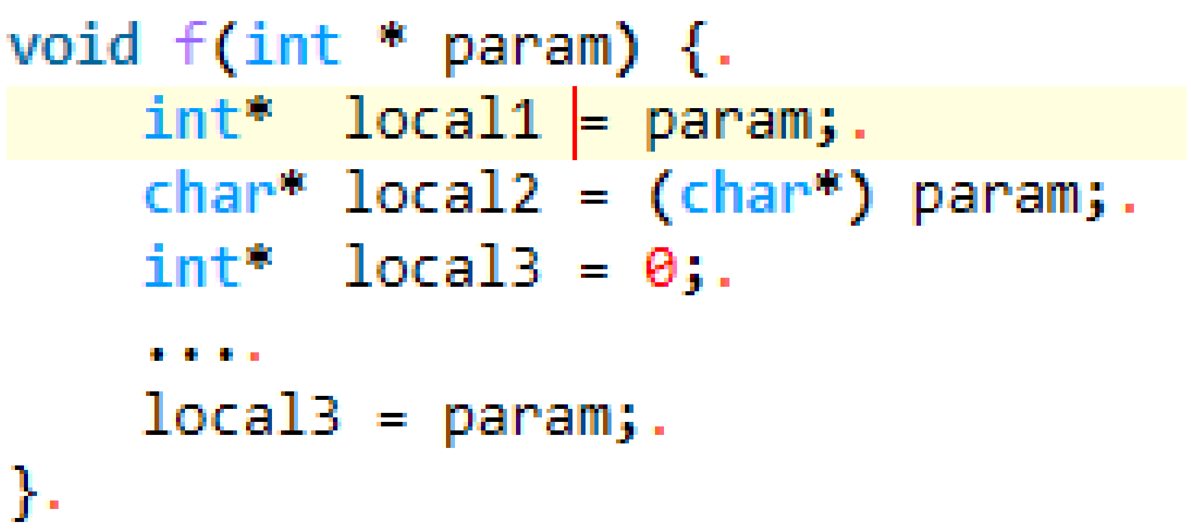
- Distinct kinds of pointers & references
  - __outer and local pointers (host, accelerator)
  - Enable output of data transfer operations
- Incompatible at the type level
  - int *p; int __outer *q;
  - p = q; // Type error
  - q = p; // Type error
  - *q = *p; // OK; data transfer!

Offload C++ and Pointers (2)

- Passing pointers/references as parameters
  - int f(int &x, int&y) { return a*b;}
  - f(a,b);
- Compiler generates duplicates on demand
  - offload int f(int &x, int&y) { return a*b;}
  - offload int f(int _outer&x, int&y) { return a*b;}
  - offload int f(int &x, int _outer&y) { return a*b;}
  - offload int f(int _outer&x, int _outer&y) { return a*b;}

Type Inference in Functions

- Inference propagates __outer
  - across initialisation
  - and casts
- Inference failure leads to compile error



```
void f(int * param) {
    int*  local1 = param;
    char* local2 = (char*) param;
    int*  local3 = 0;
    ...
    local3 = param;
}
```

Accelerator Specific features

- How to use non-portable features directly?
- In an offload context:
  - – inside an offload block, or in a function called directly or indirectly inside an offload block
- Dual C++ dialects
  - – host and accelerator
  - – Allow accelerator dialect in an offload context

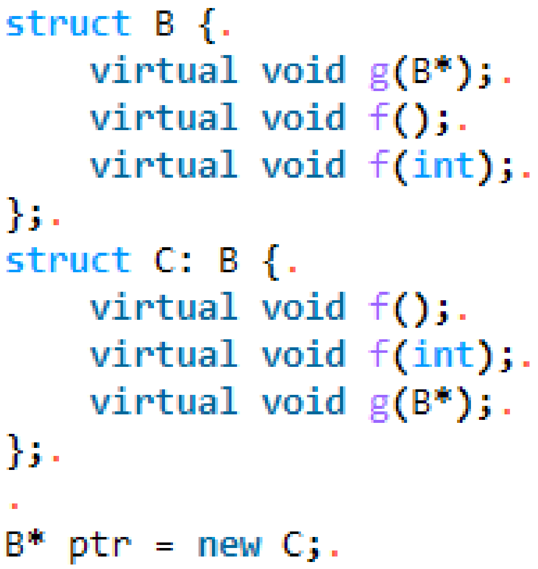
Overloading Call Graph Duplication

- Overload portable functions
  - void f() {...};
  - offload void f() {...};
- Overload selected function duplicates
  - void f(int *p, int *q) {...};
  - offload void f(int *p, int *q) {...};
- offload functions callable in an offload context

Offloading Virtual Methods

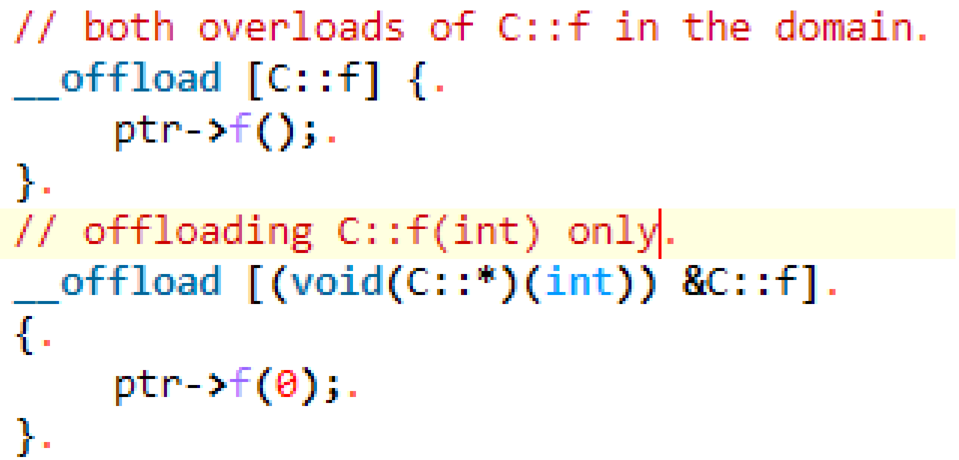
- Call graph duplication of late bound calls
  - function pointers / virtual methods
- Limited code space
- Offload block ‘domains’
  - select functions to duplicate for indirect calls
  - Lookup accelerator implementation via host address

Domains Example



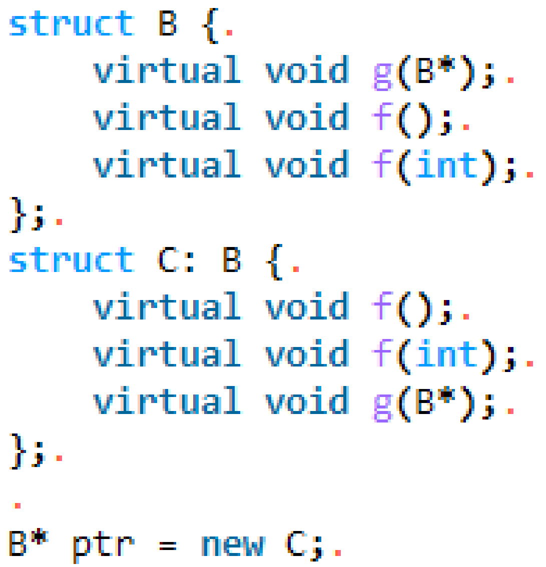
```
struct B {
    virtual void g(B*);
    virtual void f();
    virtual void f(int);
};
struct C: B {
    virtual void f();
    virtual void f(int);
    virtual void g(B*);
};

B* ptr = new C;
```



```
// both overloads of C::f in the domain.
__offload [C::f] {
    ptr->f();
}
// offloading C::f(int) only
__offload [(void(C::*)(int)) &C::f]
{
    ptr->f(0);
}
```

Domains Example



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    virtual void g(B*);
    virtual void f();
    virtual void f(int);
};
struct C: B {
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B* ptr = new C;
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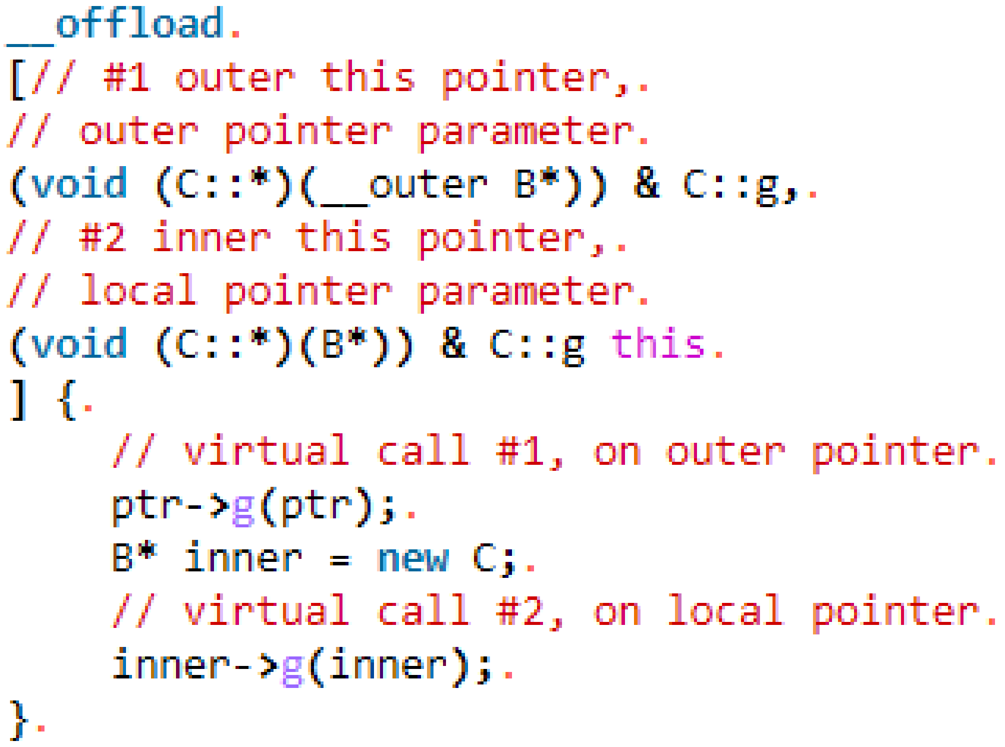


```
__offload
[// #1 outer this pointer,
// outer pointer parameter
(void (C::*)(__outer B*)) & C::g,
// #2 inner this pointer,
// local pointer parameter
(void (C::*)(B*)) & C::g this
] {
    // virtual call #1, on outer pointer
    ptr->g(ptr);
    B* inner = new C;
    // virtual call #2, on local pointer
    inner->g(inner);
}
```

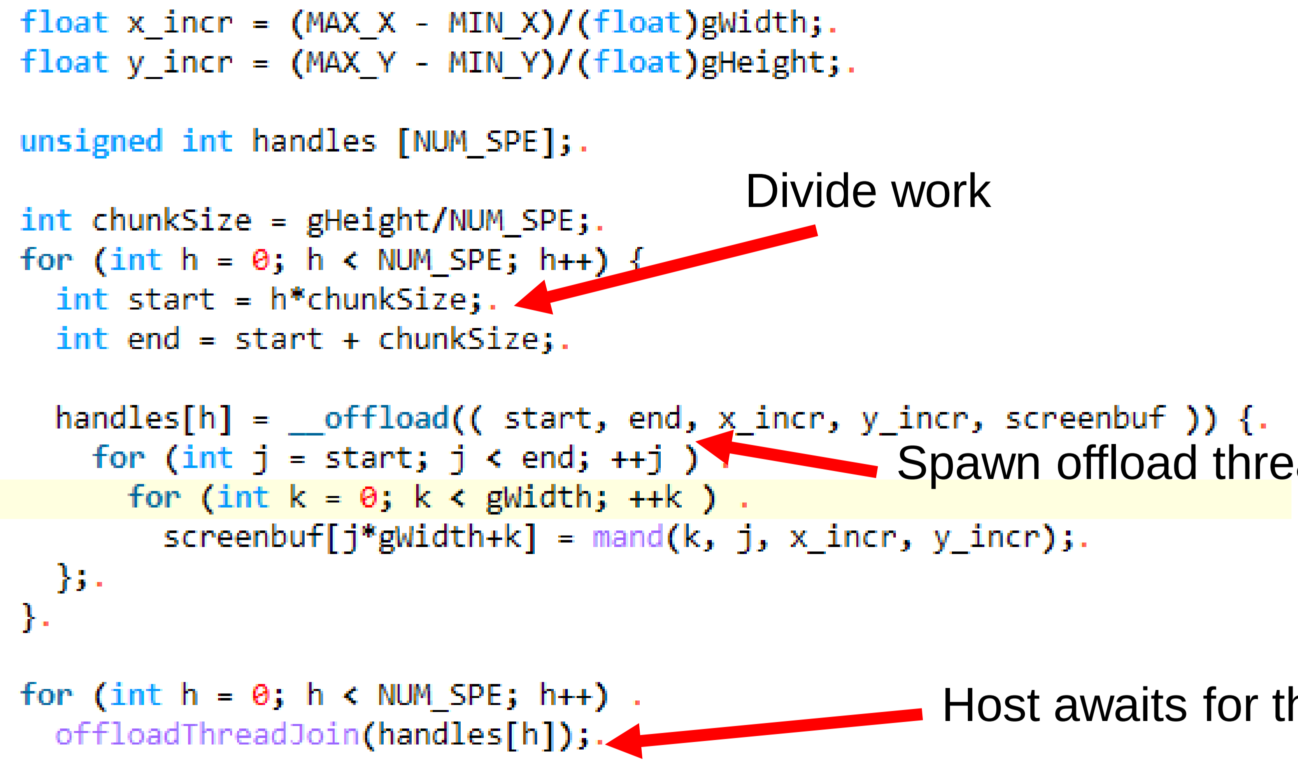
Offloading in Large Codebases

- Duplication of functions across compilation units
  - Extended function attributes
- Calling host only routines
  - Duplication requires source code
- Overlays
  - Support for limited accelerator code memory

Offloading Methodology

1. Get code on the accelerator
2. Tune for performance on a single accelerator
3. Algorithm restructuring and inlining
4. Accelerator specific optimisations
5. Parallelise

Offloading to Accelerators



```
float x_incr = (MAX_X - MIN_X)/(float)gWidth;
float y_incr = (MAX_Y - MIN_Y)/(float)gHeight;

unsigned int handles [NUM_SPE];

int chunkSize = gHeight/NUM_SPE;
for (int h = 0; h < NUM_SPE; h++) {
  int start = h*chunkSize;
  int end = start + chunkSize;

  handles[h] = __offload(( start, end, x_incr, y_incr, screenbuf )) {
    for (int j = start; j < end; ++j )
      for (int k = 0; k < gWidth; ++k )
        screenbuf[j*gWidth+k] = mand(k, j, x_incr, y_incr);
  };
}

for (int h = 0; h < NUM_SPE; h++)
  offloadThreadJoin(handles[h]);
```

Divide work

Spawn offload threads

Host awaits for thread exits

Offload C++ for Cell BE

- PS3® GameOS and Cell Linux
- Optimising Single Source C++ Compiler
  - Interoperable with GCC
  - Altivec®, Cell intrinsics
  - Generates C with Cell intrinsics / data types
  - Translates PPE vmx to SPE simd

Ease of Offloading

- Offloading should be quick, easy
- Applied to a AAA PS3® Game Renderer
  - In two hours
  - ~800 functions
  - ~170KB SPE object code
  - ~45% of host performance on a single SPE
- Plenty of scope for Cell specific optimisations to follow that

Conclusion

- Future work
  - GPU, Other, Compile to OpenCL.
- Offloading can be simple
  - even late bound calls across compilation units
  - complex dynamic data structure processing
  - type checking data transfer code
  - no extensive modifications to code
  - can use accelerator specific code too

Questions?

Offload C++ for Cell

- http://offload.codeplay.com/

Offloading Methodology (1)

- Enclose the code in an offload scope
  - Assist compiler if needed to compile
  - Add domain entries for late bound calls
- Use syntax extensions in macros
  - Compare offload versus host code
  - Keeps code portable to other compilers
- Check behaviour / performance vs host

Offloading Methodology (2)

- Reduce offload accesses to host memory
  - default access is via a software cache
  - offload block arguments
  - Make effective use of fast local storage
  - typesafe templates for data access use cases
- Compiler can report outer accesses

Offloading Methodology (3)

- Compiler optimisation
    - e.g. inlining
- Algorithm restructuring
    - portable code may not be good on accelerator
    - accelerator cores specialised

Offloading Methodology (4)

- Accelerator specific optimisations
  - Introduce non-portable code
- Needs some expertise
  - SIMDize code
  - Restructure data for efficient access
  - Consider data transfer strategies
    - e.g. double buffering
- Like directly programming the accelerator

Offloading Methodology (5)

- Parallelise for multiple accelerators
  - Similar to multi-threading
- If already parallelised, offload the threads
- Target threads for available accelerators
- May be worth parallelising before optimising individual offloads