Hands on with Arm Tools

GoingArm, HiPEAC 2018

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Outline

- Outcomes of the hands-on
- Introduction to Arm tools
  - HPC Compiler
  - Performance Libraries
  - Performance analysis tools
- Introduction to hands on-material

Outcomes

- In this session you will:
  - Work on single-node Arm hardware (Cavium ThunderX)
  - Use the Arm compiler to generate a binary
  - Use flags to generate different binaries and compiler advice
  - Use the Arm Performance Libraries for optimal performance
  - Observe performance data in the Arm MAP performance analysis tool

Arm HPC Compiler

- C / C++ and Fortran support
  - armclang
  - armclang++
  - armflang
- Based on LLVM
- Optimized for HPC use cases
- Just like any other compiler – easy to pick up in this session

Arm Performance Libraries

- Optimized BLAS, FFT, etc for many-core nodes
- Specialized support for Arm instruction set architectures
- Specialized support for specific hardware

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Arm Performance Analysis

- Multi-architecture support for debugging and performance analysis
- Scalable (many thousands of nodes), low-overhead and easy to use
- Timeline of application behavior

Hands-on Material

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Tutorial Problem

- Matrix-matrix multiplication in C/C++:
  - Focus not on understanding the problem, but how to use the Arm toolchain
  - Naïve to optimized performance
- Program flow
  - Initialize random data
  - Perform multiply
- Use of compiler for single core and multi-core application
- Understanding of application performance

Matrix-Matrix Multiply: Version 1

- Naïve implementation works on single core
- No consideration of underlying hardware

```
for (i= 0; i < n; ++i){
    for (j= 0; j < l; ++j){
        for (k= 0; k < m; ++k){
            matC[i][j] += matA[i][k] * matB[k][j];
        }
    }
}
```

- How bad is performance? Easier to evaluate when compared to other code

Matrix-Matrix Multiply: Version 2

- Add blocking to be able to take advantage of cache

```
for (kk= 0; kk < m; kk+= blockSize){
    for(jj= 0; jj < l; jj+= blockSize){
        for(i= 0; i < n; i+= 2){
            for(j= jj; j < min(l, jj + blockSize); j+= 2){
                for(k =kk; k < min(m, kk + blockSize); ++k){
                    matC[i][j] += matA[i][k] * matB[k][j];
                    matC[i][j+1] += matA[i][k] * matB[k][j+1];
                    matC[i+1][j] += matA[i+1][k] * matB[k][j];
                    matC[i+1][j+1] += matA[i+1][k] * matB[k][j+1];
                }
            }
        }
    }
}
```

- Have only added one level of blocking, which can take advantage of a single level of cache only
- Also little bit of loop unrolling to allow re-use of registers

Matrix-Matrix Multiply: Version 2

- Add blocking to be able to take advantage of cache

```
for (kk= 0; kk < m; kk+= blockSize){
    for(jj= 0; jj < l; jj+= blockSize){
        for(i= 0; i < n; i+= 2){
            for(j= jj; j < min(l, jj + blockSize); j+= 2){
                for(k =kk; k < min(m, kk + blockSize); ++k){
                    matC[i][j] += matA[i][k] * matB[k][j];
                    matC[i][j+1] += matA[i][k] * matB[k][j+1];
                    matC[i+1][j] += matA[i+1][k] * matB[k][j];
                    matC[i+1][j+1] += matA[i+1][k] * matB[k][j+1];
                }
            }
        }
    }
}
```

- Performance improvement of greater than 2x at 1024x1024 with 128 block size
- Still tens of seconds to perform a small multiply – bring out the big guns

Matrix-Matrix Multiply: Version 3

- Use Arm Performance Libraries
  - Addition of –larmpl flag to build command
  - Standard BLAS interface

```
cblas_dgemm(CblasRowMajor, CblasNoTrans, CblasNoTrans, n, m, l, 1, dataA,
        m, dataB, l, 1, dataC, m);
```

- Approximately 17x speed-up over blocked multiply and 40x over naïve implementation
- Still almost at a second run time at small 1024x1024 matrix

Matrix-Matrix Multiply: Version 4

- Have 96 physical cores available on the system – make use of them
- OpenMP directives added to loops
- Link to parallel version of the Arm Performance Libraries (-larmpl_mp)

```
#pragma omp parallel for private(i, j, jj, k, kk)
    for (kk= 0; kk < m; kk+= blockSize){
        for(jj= 0; jj < l; jj+= blockSize){
            for(i= 0; i < n; i+= 2){
                for(j= jj; j < min(l, jj + blockSize); j+= 2){
                    for(k =kk; k < min(m, kk + blockSize); ++k){
                        matC[i][j] += matA[i][k] * matB[k][j];
                        matC[i][j+1] += matA[i][k] * matB[k][j+1];
                        matC[i+1][j] += matA[i+1][k] * matB[k][j];
                        matC[i+1][j+1] += matA[i+1][k] * matB[k][j+1];
                    }
                }
            }
        }
    }
```

Matrix-Matrix Multiply: Version 4

- Have 96 physical cores available on the system – make use of them
- Small matrix size means not all threads can be used with simple OpenMP directive
- Arm Performance library utilizes all threads – approximately 100x faster than blocking approach

```
#pragma omp parallel for private(i, j, jj, k, kk)
    for (kk= 0; kk < m; kk+= blockSize){
        for(jj= 0; jj < l; jj+= blockSize){
            for(i= 0; i < n; i+= 2){
                for(j= jj; j < min(l, jj + blockSize); j+= 2){
                    for(k =kk; k < min(m, kk + blockSize); ++k){
                        matC[i][j] += matA[i][k] * matB[k][j];
                        matC[i][j+1] += matA[i][k] * matB[k][j+1];
                        matC[i+1][j] += matA[i+1][k] * matB[k][j];
                        matC[i+1][j+1] += matA[i+1][k] * matB[k][j+1];
                    }
                }
            }
        }
    }
```


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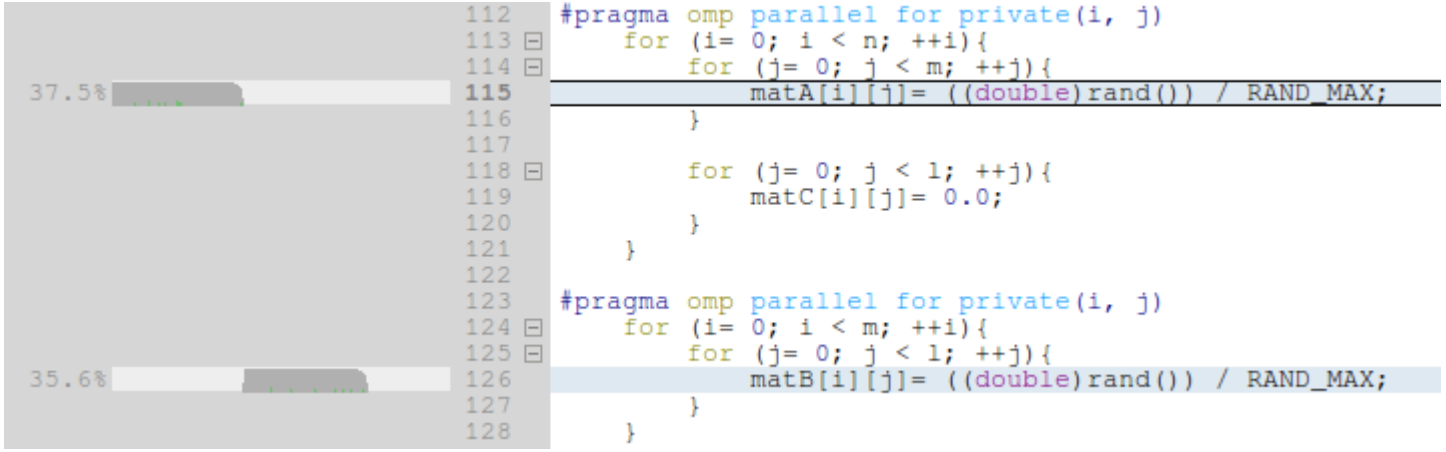
Matrix-Matrix Multiply: Version 4 (Interlude)

- Time to populate matrices with random data much higher when using OpenMP
- Use Arm Forge (performance analysis toolset) to investigate



- Lots of time spent waiting on the kernel in glibc rand function
  - Kernel lock being held means that parallel performance can't be obtained

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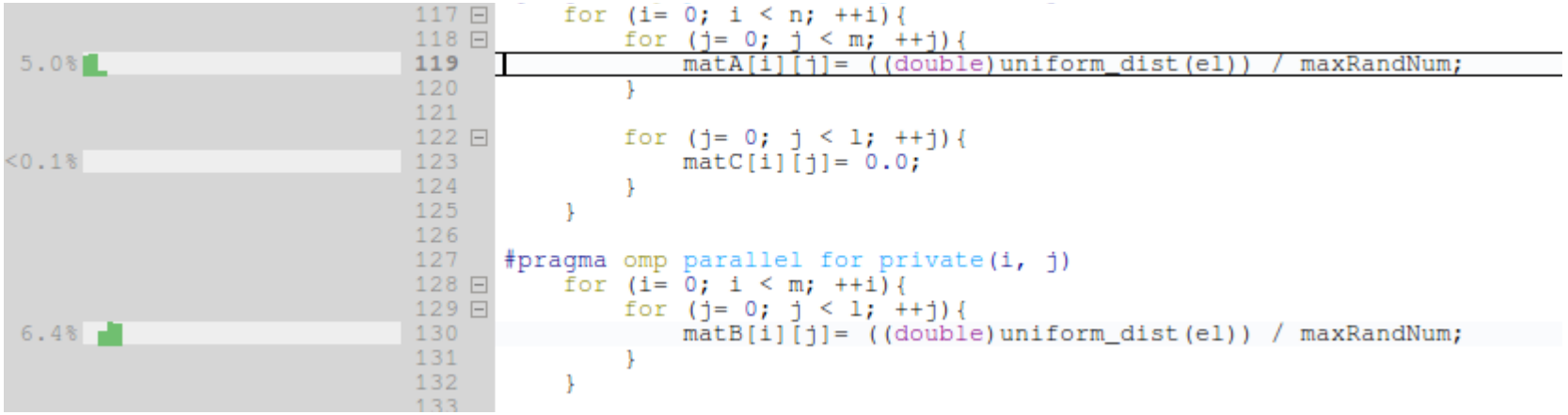
Matrix-Matrix Multiply: Version 5 (Interlude)

- Update random function to be thread safe implementation (e.g. C++ stdlib functions)



- Can make use of all cores in parallel

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Matrix-Matrix Multiply: Version 6

- Allow compiler to make better decisions on loop parallelism

```
#pragma omp parallel for collapse(2) private(i, j, jj, k, kk)
    for (kk= 0; kk < m; kk+= blockSize){
        for(jj= 0; jj < l; jj+= blockSize){
            for(i= 0; i < n; i+= 2){
                for(j= jj; j < min(l, jj + blockSize); j+= 2){
                    for(k =kk; k < min(m, kk + blockSize); ++k){
                        matC[i][j] += matA[i][k] * matB[k][j];
                        matC[i][j+1] += matA[i][k] * matB[k][j+1];
                        matC[i+1][j] += matA[i+1][k] * matB[k][j];
                        matC[i+1][j+1] += matA[i+1][k] * matB[k][j+1];
                    }
                }
            }
        }
    }
```

- Allows better use of threads – 8x speed-up over not using collapse directive
- Still greater than 10x slower than Arm Performance Libraries

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Matrix-Matrix Multiply: Version 7

- Lots of improvements to be made in the simple implementation of matrix-matrix multiply
  - Consideration of all levels of cache
  - Hardware specific block size
  - Use of vectorisation
- Compiler can auto-vectorize. Does it in this case?
  - Add –Rpass-analysis=loop-vectorize for report on vectorization

```
mat_mult_7.cpp:48:21: remark: loop not vectorized: cannot identify array bounds [-Rpass-analysis=loop-vectorize]
                  for(k =kk; k < min(m, kk + blockSize); ++k){
                  ^
mat_mult_7.cpp:47:17: remark: loop not vectorized: could not determine number of loop iterations [-Rpass-analysis=loop-vectorize]
                for(j= jj; j < min(l, jj + blockSize); j+= 2){
                ^
```

Further Exercises

- Have a play around with the code provided – can you get vector instructions generated? https://goo.gl/NN7KsC

- Consider compiler flags – do your favourite GNU and Intel flags exist for Arm?
- https://goo.gl/orhZEu and https://goo.gl/FKAjwP

- Consider the performance profiles generated by the Arm Forge tools – what do they tell you about the performance of the executables? https://goo.gl/PaeA2N

- Links to extra material in the Tutorial Walkthrough – Final Summary

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Hands on - The instructions

Instructions available on Google Docs (https://goo.gl/mQaMb3)

Thank You!
Danke!
Merci!
谢谢!
ありがとう!
Gracias!
Kiitos!
감사합니다
धन्यवाद