Evaluation and Exploration of Next Generation Systems for Applicability and Performance

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Plan of work for Q3

• **Within the doc2learn framework**
  • re-implement image processing algorithm for execution on the host CPU and GPUs in C, CUDA C, and OpenCL
    • Q: Why only image processing?
    • A: this is deemed to be the most compute- and data-intensive task in doc2learn
  • study performance
  • quantify potential benefits
  • develop plans for the follow-up work
Computes probability density function (basically histogram) for images

(Optimized) Java implementation

```java
int red, green, blue;
byte[] data = ((DataBufferByte)bi.getRaster().getDataBuffer()).getData();
for (int i = 0; i < data.length; i+=3){
    red = (data[i] & 0xff) / size;
    green = (data[i+1] & 0xff)/ size;
    blue = (data[i+2] & 0xff) / size;
    histogram[red][green][blue]++;
}
```

Original Java implementation of the computational kernel
C implementation for Intel/AMD host

- Java calls C function (using JNI interface)
  - C function copies data and does the work
- Java function collects results afterwards

### Diagram

- Original Java implementation of the computational kernel
- Call C function
- C function executed on the CPU host
- Copy results

**Actual application time**

**CPU time**
CUDA C/OpenCL Implementation for NVIDIA and AMD GPUs

- **Java calls C function**
  - C function copies data from Java VM
  - C function copies data to the GPU memory and calls a GPU kernel
    - GPU computes
  - C function copies data from GPU memory
- **Java function collects results afterwards**

![Diagram of data transfer and kernel execution](image)
Stand-alone test for varying image size (all overheads included)

![Image size vs execution time graph]

- Blue line: Java on 2.8 GHz AMD Istanbul
- Red line: Java on 3.3 GHz Intel Core i7
- Green line: C on 2.8 GHz AMD Istanbul
- Magenta line: C on Intel 3.3 GHz Core i7
- Cyan line: GPU CUDA on NVIDIA GTX 480
- Orange line: GPU OpenCL on NVIDIA GTX 480
- Blue line: GPU OpenCL on ATI Radeon HD5870
Speedups
(with and without overheads)

- C to Java speedup on Intel 3.3 GHz Core i7 (with JNI overhead)
- C to Java speedup on Intel 3.3 GHz Core i7 (without JNI overhead)
- NVIDIA GTX 480 GPU to Intel 3.3 GHz Core i7 (C) speedup (with PCIe overhead)
Synthetic dataset test

100x100 pixels images

200x200 pixels images
Does it really matter? (Java only example run)

Entire application profile
- object extraction 66%
- PDF file parsing 25%
- processing time 7%
- results storage 1%
- miscellaneous 1%

Data analysis profile
- text, 138 ms
- image, 274 ms
- graphic, 20 ms
Does it really matter? (Java + C example run)

Entire application profile

- Object extraction 68%
- PDF file parsing 25%
- Miscellaneous 1%
- Results storage 1%
- Processing time 5%

Data analysis profile

- Text, 138 ms
- Image, 109 ms
- Graphic, 20 ms
Does it really matter? 
(Java + C + NVIDIA GPU example run)

Entire application profile

Data analysis profile

PDF file parsing 26%
object extraction 68%
results storage 1%
miscellaneous 1%
processing time 4%

graphic, 20 ms
image, 73 ms
text, 138 ms

26% object extraction
68% processing time
Conclusions

• **Implications for doc2learn image analysis algorithm**
  • The image probability density function computation algorithm implemented in Java in doc2learn software can be accelerated by a factor of 6x if the entire doc2learn image analysis software is re-implemented in C,
  • Or by a factor of almost 16x if it also uses an NVIDIA GTX 480 GPU.
  • Actual GPU speedup largely depends on the image size; for images less than 512x512 a properly done CPU implementation will outperform a GPU implementation.
  • Calling a GPU-based implementation from the existing doc2learn Java-based code is still beneficial as it provides up to 4x speedup for sufficiently large images.
  • But another factor of 4x speedup can be achieved by porting the entire image analysis software suite to C and using GPU kernels within the C-based code. Java is not really a high-performance platform for this sort of computations.
Conclusions

• Implications for doc2learn application
  • Doc2learn execution profile indicates that only about 4% of the overall execution time for the given pdf file example is spent on the image processing part. Speeding it up by any factor will not make much of a difference for the entire application.
    • Said that, GPU acceleration may be still beneficial for pdf files containing very large images or embedded videos.
  • Doc2learn also implements probability density function computation algorithms for text and vector graphics. These data types exhibit less regular memory access patterns and require much large histograms to be stored. Because of this, they are less suitable for GPU implementation as compared to image histograms.
Conclusions

• **CUDA vs OpenCL**
  - At this point, CUDA-based implementation outperforms the OpenCL based implementation, but it does not provide portability across GPU platforms.
  - We have not investigated OpenCL implementation for a multi-core architecture, but from our prior experience we know that platform-specific tuning will be required to achieve good performance with OpenCL on any architecture. The OpenCL code written for one architecture will execute on another architecture, but typically not at its full potential.
  - Thus, in light of
    - poorer performance of OpenCL implementation
    - immaturity of the OpenCL tools
    - need for architecture-specific code tuning, and
    - overall impact on the doc2learn application performance
  - benefits of OpenCL implementation of the probability density function are minor.
Work in progress

- Develop a stand-alone C test-bed of the image extraction component of doc2learn
  - integrate the developed image probability density function computation algorithm (both the CPU and GPU implementations)
  - investigate how to extend the CPU implementation of the histogram computation to the multi-core architecture of modern CPUs
  - conduct a study how the stand-alone implementation compares to the original doc2learn Java-based implementation
  - use the stand-alone framework to analyze power consumption of the CPU and GPU implementations

- Investigate other image comparison algorithms and their suitability for GPU acceleration

- Investigate pros and cons of extending Versus framework to use GPU-based image processing algorithms