Dominoes: Exploratory Data Analysis of Software Repositories Through GPU Processing

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Introduction

- Identifying expertise is important:

- Normally, expertise is identified through informal process:
  - Social network
  - Implicit knowledge of work dependencies
- Even more challenging in globally distributed development

Introduction

- Software development leaves behind the activity logs for mining relationships
  - Commits in a version system
  - Tasks in a issue tracker
  - Communication
- Finding them is not a trivial task
  - There is an extensive amount of data to be analyzed
  - Data is typically stored across different repositories
- Scalability problems depending on the project size
  - Processing the history of large repositories at fine grain for exploratory analysis at interactive rate

Related Work

- EEL scope the analysis to 1,000 project elements
  - Restrict the history to small chunk of data
- Cataldo analyze data at coarse-grain
  - Developer is expert of the whole artifact
- Boa allows fine-grain analysis by using a CPU cluster
  - Normally require a time slice for using the cluster
  - Require data submission for processing

Solving the Problem

Performance

Implement used operations for data analysis in GPU

+

Usability

User interface

=

Deeper Research

Happy user / researcher

Solving the Problem

- Efficient large-scale repository analysis
- Enable users to explore relationships across different levels of granularity
- No requirement for a specialized infrastructure

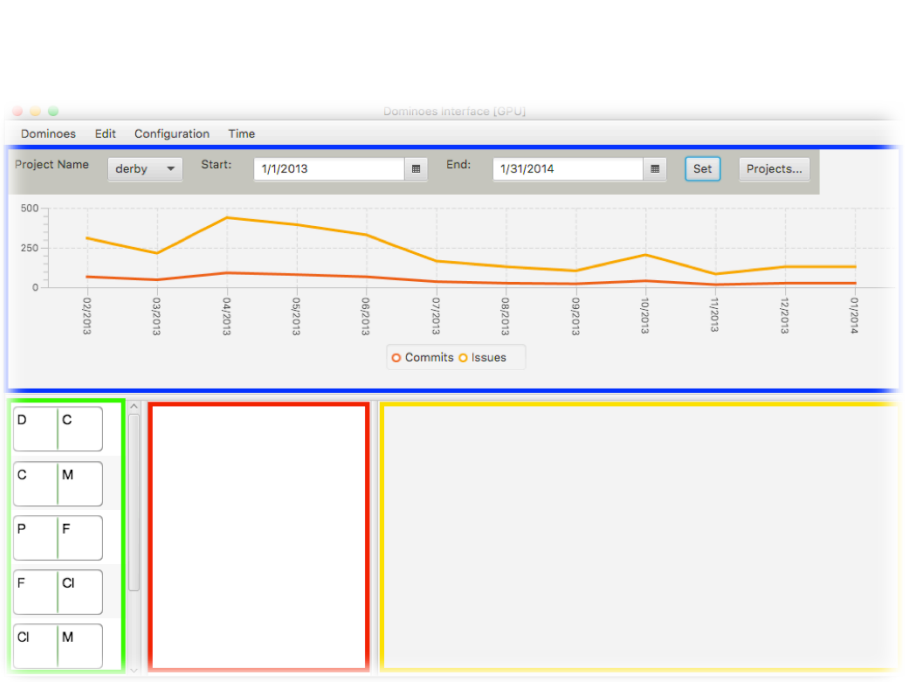
Dominoes

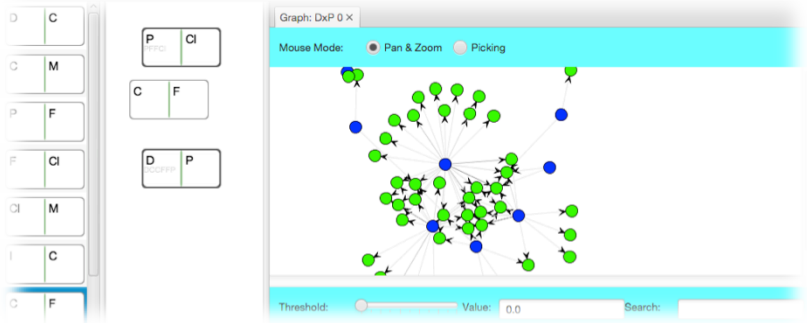
- Infrastructure that enables interactive exploratory data analysis at varying levels of granularity using GPU

- Organizes data from software repositories into multiple matrices
  - Each matrix is treated as Dominoes tile
  - Tiles can be combined through operations to generate derived tiles
    - Transposition, multiplication, addition, …

Dominoes UI

- Dominoes' tiles resemble a Dominoes game, where the user can play with to build new relationships





Basic Building Tiles

[developer|commit]

[package|file]

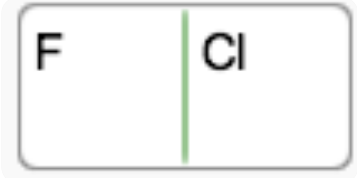
[commit|file]

[class|method]

[issue|commit]

[commit|method]

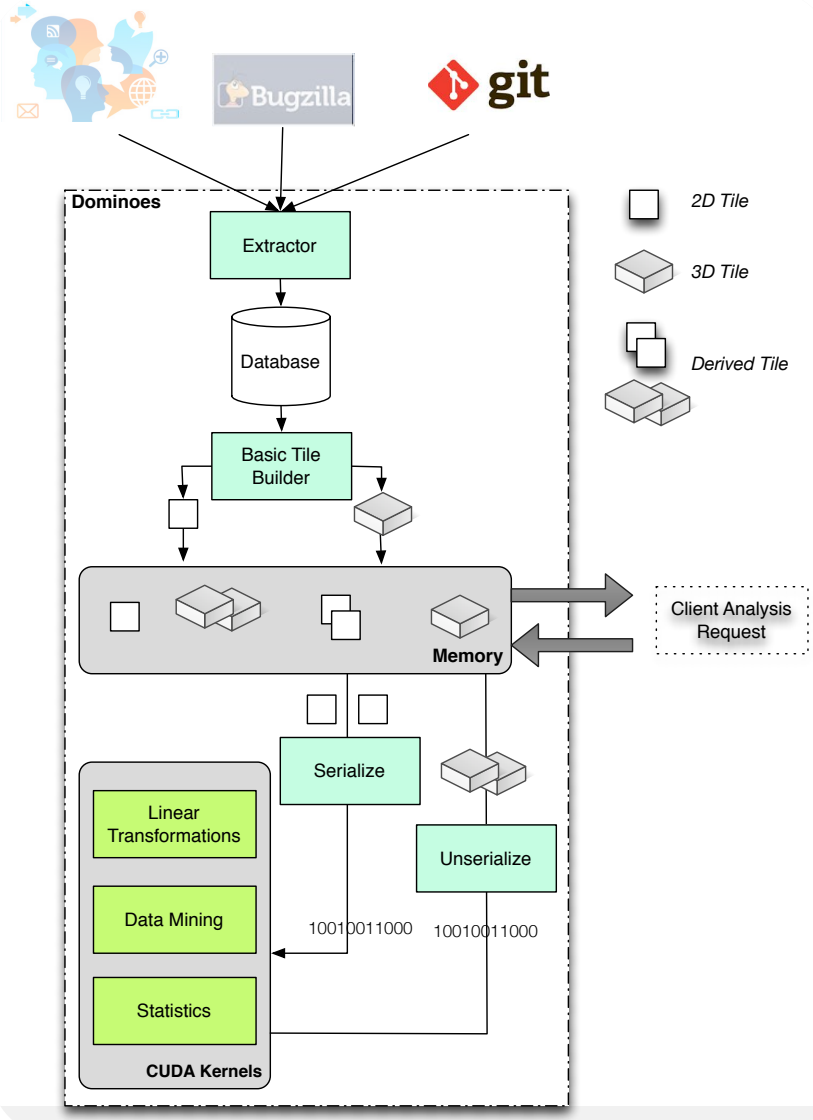
[file|class]



Examples of Derived Building Tiles

- **[method|method] (MM = CM^T × CM)**: represents method dependencies
- **[class|class] (ClCl = CIM × MM × CIM^T)**: represents class dependencies
- **[issue|method] (IM = IC × CM)**: represents the methods that were changed to implement/fix an issue

Dominoes Architecture



- **Extractor module** gather information from repository and save to database
- **Basic block builder** is responsible to generate building blocks relationship from database
- Operations are performed in GPU using a **Java Native Interface** call
- Derived and basic building block **still in memory** for future use

Data Structure

Java

```
…
long pointer m1, m2, res;
createObj(res);
multiplication(m1, m2, res)
…
```

C / CUDA

```
void multiplication(JNIEnv *env, jclass obj,
        jlong m1, jlong m2, res )
{
   Matrix *_m1 = (Matrix*) m1;
   Matrix *_m2 = (Matrix*) m2;
   Matrix *_res = (Matrix*) m2;
   GPUMul(m1, m2, _res);
}
```

- Matrix are very sparse for some relationships
  - Developer x Commit
- The java side maintain a pointer to the sparse matrix allocated in C side
  - The matrix are stored in CRS format
- Matrix operations performed in C using a JNI interface

Operations in GPU

Linear Transformation

Addition
Multiplication
Transposition

Data Mining

Confidence
Lift
Support

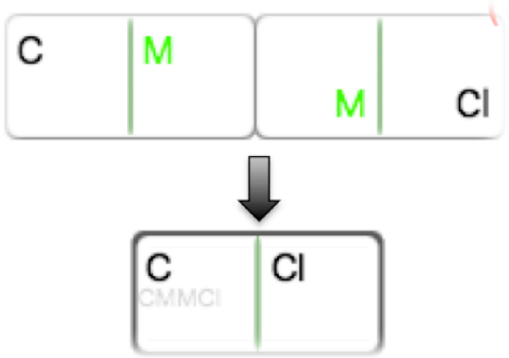
Statistics

Mean
Standard Deviation
Z-Score

Linear Transforms

- Allows connecting pieces in the Dominoes by changing its edge

- Allows extracting further relationships in the data by combining the different types of data



- Uses cusp library for performing linear transforms

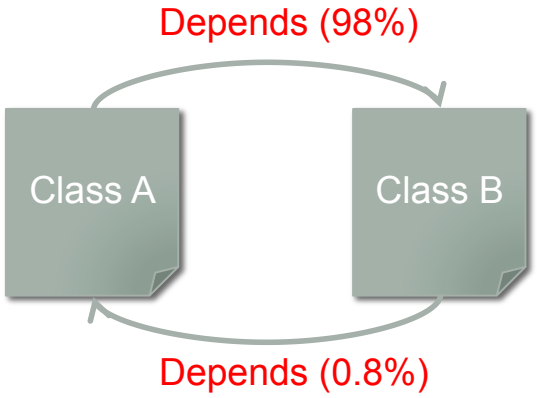
Reduction

- Normally used for calculating the amount of relationship
  - Total of classes modified by a developer
  - How many bugs a developer have inserted in a method Y

- Uses the Thrust library for calculating it in GPU

Confidence

- Used to detect the relationship direction



- Each GPU thread is responsible for processing the confidence for each element

$$M^{conf}[i,j] = \frac{M^{SUP}[i,j]}{M^{SUP}[i,i]}$$

Confidence

- Due to the fact that the row and column must be know, they are computed and stored in a vector.
- Given a sparse $M \times M$ with t non zero values:

For each ***t*** GPU thread

```
diagIdx = row[idx];
conf[idx] = value[idx] / diagonal[diagIdx]
```

Z-Score

- Responsible to convert an absolute value to a score above the mean

$$z = \frac{(x - \mu)}{\sigma}$$

x = *absolute score*
μ = *mean*
σ = *standard deviation*

- Require a set of steps
  - Calculating the mean / column
  - Calculating the standard deviation
  - Finally calculating the z-score

Z-Score

- Calculating the mean / column
  - Given a Matrix *M* × *N*, containing *t* non zero values, the GPU is responsible to sum up all values for a column, producing a vector sized *N* for the mean.

Value

Col

Kernel 1

For each ***t*** GPU thread

```
colIdx = col[idx]
atomicAdd(value[idx],
sum[idx])
atomicAdd(1, count[idx])
```

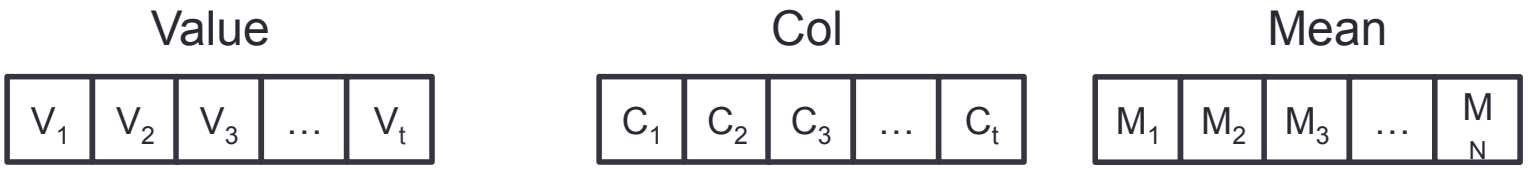
Kernel 2

For each ***N*** GPU thread

```
mean[idx] = sum[idx] / count[idx]
```

Z-Score

- Calculating the standard deviation / column
  - Given a Matrix *M* × *N*, the GPU is responsible to sum up all values for a column, producing a vector sized *N* for the standard deviation



Kernel 1

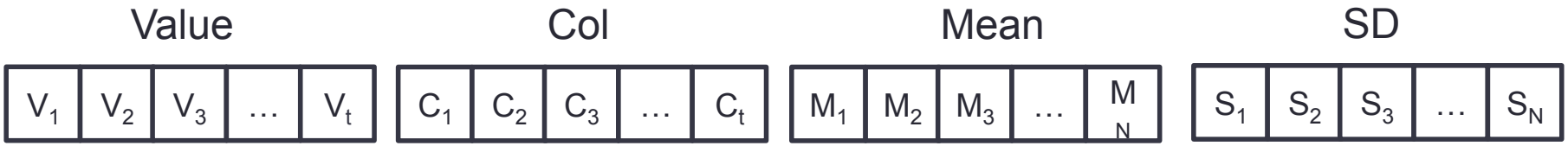
For each ***t*** GPU thread
colIdx = col[idx]
colMean = mean[colIdx]
deviate = value[idx] – colMean
deviatePower2 = deviate * deviate
atomicAdd(deviatePower2, variance[colIdx])

Kernel 2

For each ***N*** GPU thread
colVariance = variance[idx]
colVarianceSqrt = sqrt(colVariance / M)
deviation[idx] = colVarianceSqrt

Z-Score

- Calculating the standard score
  - Given a Matrix *M* × *N* with *t* non zero elements, the GPU is responsible to produce the z-score

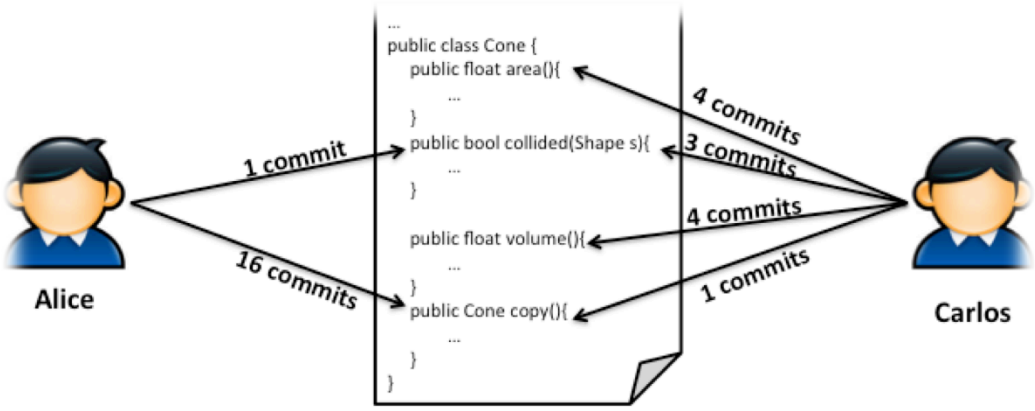


For each ***t*** GPU thread
  colIdx = col[idx]
  colMean = mean[colIdx]
  standardDev = sd[colIdx]
  z = (value[idx] – colMean) / standardDev
  zscore[idx] = z

Applicability

Dependency Identification

Expertise Identification



Expertise breadth identification

Results

- Evaluation time (support and confidence).
  - [file|commit] (34,335 x 7,578)
    - CPU: 696 minutes | GPU: 0.7 minutes | Speed up: 994
  - [method|commit] (305,551 x 7,578)
    - CPU: N/A | GPU: 5 minutes | Speed up: -

** Intel Core 2 Quad Q6600 2.40GHz PC with 4GB RAM and a nVidia GeForce GTX580 graphics card was used.*

Results

- **[Developer|File|Time]:** 114 layers of 36 x 3400 (13,953,600 elements)
- **[Developer|Method|Time]**: 114 layers of 36 x 43,788 (179,705,952 elements)

	EBD when Considering Files (seconds)			EBD when Considering Methods (seconds)		
	Mean & SD	**Z-Score**	**Total**	**Mean & SD**	**Z-Score**	**Total**
CPU	2.19	301.23	303.42	424.71	1,573,60	1,998.31
GPU	0.10	19.49	19.59	8.55	203.46	212.01
Speed Up	21.90	15.45	15.48	49.67	7.73	9.42

** EBD = Expertise Breadth of a Developer.*

Results

- J. R. da Silva, E. Clua, L. Murta, and A. Sarma. Niche vs. breadth: **Calculating expertise over time through a fine-grained analysis**. In Software Analysis, Evolution and Reengineering (SANER), 2015 IEEE 22nd International Conference on, pages 409–418, Mar. 2015

- J. R. da Silva, E. Clua, L. Murta, and A. Sarma. **Multi-Perspective Exploratory Analysis of Software Development Data**. International Journal of Software Engineering and Knowledge Engineering, 25(01):51–68, 2015.

- J. R. da Silva Junior, E. Clua, L. Murta, and A. Sarma. **Exploratory Data Analysis of Software Repositories via GPU Processing**. 26th SEKE, 2014

Conclusions

- The main contribution is using GPU for solving Software Engineering problems
- Employment of GPU allows seamless relationship manipulations at interactive rates
  - Uses matrices underneath to represents building blocks
- Dominoes opens a new realm of exploratory software analysis, as endless combinations of Dominoes' pieces can be experimented in an exploratory fashion
- Thanks to the use of GPU, the user can do its analysis on its own machine

Questions

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