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Parallelizing Operations with Ease Using Parallel SPOT

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Overview

- Motivation
- Parallel Computing Toolbox - Matlab
- Parallel SPOT
- Examples & Demo

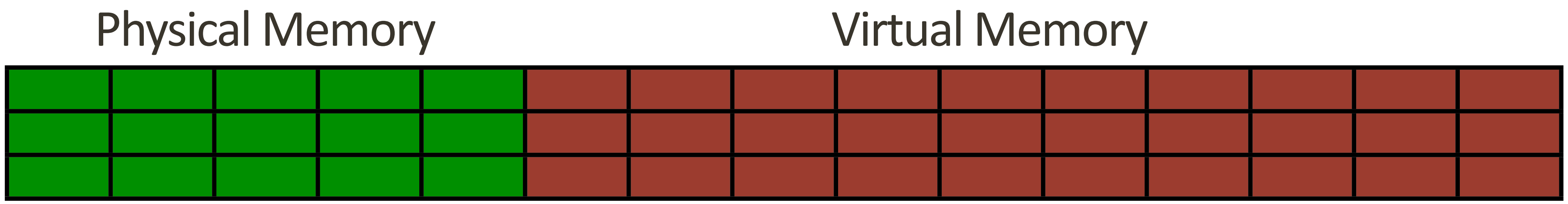
Motivation

Limitations of a single system

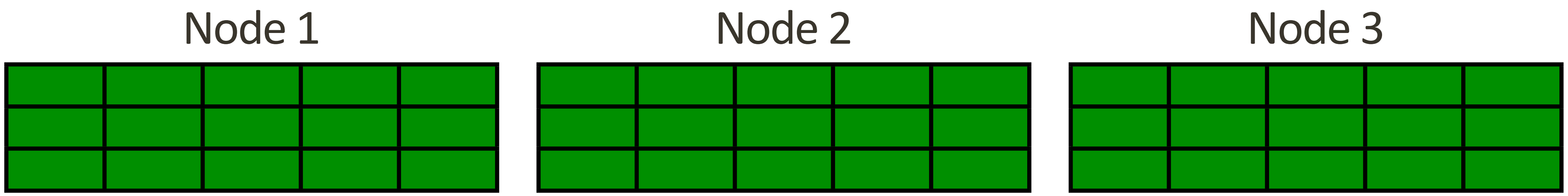
- Memory -- problem size
- Processing power -- speed

Increasing Problem Size

- Real data is often too large to fit in memory on a single computer



- But can be split among several computers



Improving Speed

- Data-intensive operations can often be drastically sped up by distributing the work

- Situations ideal for distribution are called Embarrassingly Parallel
- Still other operations can be parallelized with some consideration

Embarrassingly Parallel

Operations you can split with little to no communication

$$\begin{bmatrix} 0 & 1 & 0 & - & - & - & - & - & - \\ 1 & 0 & 1 & - & - & - & - & - & - \\ 1 & 0 & 0 & - & - & - & - & - & - \\ - & - & - & 8 & 4 & 4 & - & - & - \\ - & - & - & 8 & 3 & 9 & - & - & - \\ - & - & - & 1 & 8 & 2 & - & - & - \\ - & - & - & - & - & - & 1 & 0 & 0 \\ - & - & - & - & - & - & 0 & 1 & 0 \\ - & - & - & - & - & - & 0 & 0 & 1 \end{bmatrix} \qquad \begin{bmatrix} 2 \\ 1 \\ 1 \\ 8 \\ 6 \\ 3 \\ 5 \\ 4 \\ 0 \end{bmatrix}$$

```
A = opBinary( 3 );      B = randi( 9, 3 );      C = opEye( 3 );
BD = opBlockDiag( A, B, C );          BD ∗ x;
```

Embarrassingly Parallel

Operations you can split with little to no communication

$$\begin{bmatrix} 0 & 1 & 0 & - & - & - & - & - & - \\ 1 & 0 & 1 & - & - & - & - & - & - \\ 1 & 0 & 0 & 8 & 4 & 4 & - & - & - \\ - & - & - & 8 & 3 & 9 & - & - & - \\ - & - & - & 1 & 8 & 2 & 1 & 0 & 0 \\ - & - & - & - & - & - & 0 & 1 & 0 \\ - & - & - & - & - & - & 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 2 \\ 1 \\ 1 \\ 8 \\ 6 \\ 3 \\ 5 \\ 4 \\ 0 \end{bmatrix}$$

A = opBinary(3);   B = randi(9, 3);   C = opEye(3);

BD = opBlockDiag(A, B, C, **1);**   BD $*$ x;

Non-Trivial Parallelizing

Requires extensive communication and planning

$$y = (A \otimes B) \times \text{vec}(X)$$

Simplified using the equality:

$$(A \otimes B) \times \text{vec}(X) = \text{vec}(B \times X \times A^T) = \text{vec}((A \times (B \times X)^T)^T)$$

Parallel Matlab

- Parallel Computing Toolbox provides constructs and data types for parallel programming

- Constructs:
  - spmd - Single Program Multiple Data
  - parfor - Parallel For loop
- Data Types:
  - Distributed/Codistributed - matrix/cell

Parallel Matlab

```
BD = distributed.cell( 1, 3 );
BD{1} = A;      BD{2} = B;      BD{3} = C;
y = cell( 3, 1 );
spmd
   block = getLocalPart( BD );
   y{ labindex } =  block * x( 1 + (labindex-1)*3 : labindex*3 );
end
y = cell2mat( y );
```

Parallel SPOT

- Is object oriented and thus **intuitive** to use
- Abstracts away the translation to parallel code
- Is written in MatLab
  - ➡interfaces directly with Java
  - ➡works well with C/C++ and Fortran
- Is an extension to SPOT
  - ➡Has the same framework
  - ➡Compatible with SPOT operators
  - ➡Inherits/overloads all the superclass functions

Parallel Block Diagonal

$$
\begin{bmatrix}
0 & 1 & 0 & - & - & - & - & - & - \\
1 & 0 & 1 & - & - & - & - & - & - \\
1 & 0 & 0 & 8 & 4 & 4 & - & - & - \\
- & - & - & 8 & 3 & 9 & - & - & - \\
- & - & - & 1 & 8 & 2 & 1 & 0 & 0 \\
- & - & - & - & - & - & 0 & 1 & 0 \\
- & - & - & - & - & - & 0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
2 \\ 1 \\ 1 \\ 8 \\ 6 \\ 3 \\ 5 \\ 4 \\ 0
\end{bmatrix}
$$

```
A = opBinary( 3 );      B = randi( 9, 3 );      C = opEye( 3 );
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BD * x;
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Parallel Block Diagonal

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A = opBinary(3);   B = randi(9, 3);   C = opEye(3);

BD = ~~opBlockDiag(A, B, C, 1);~~

BD $*$ x;

Parallel Block Diagonal

$$\begin{bmatrix} 0 & 1 & 0 & - & - & - & - & - & - \\ 1 & 0 & 1 & - & - & - & - & - & - \\ 1 & 0 & 0 & 8 & 4 & 4 & - & - & - \\ - & - & - & 8 & 3 & 9 & - & - & - \\ - & - & - & 1 & 8 & 2 & 1 & 0 & 0 \\ - & - & - & - & - & - & 0 & 1 & 0 \\ - & - & - & - & - & - & 0 & 0 & 1 \end{bmatrix} \quad \begin{bmatrix} 2 \\ 1 \\ 1 \\ 8 \\ 6 \\ 3 \\ 5 \\ 4 \\ 0 \end{bmatrix}$$

A = opBinary(3); B = randi(9, 3); C = opEye(3);

BD = ~~opBlockDiag(A, B, C, 1);~~ oppBlockDiag(A, B, C, 1);

BD $*$ x;

Parallel Kronecker

$$(A \otimes B) \times \mathrm{vec}(X) = \mathrm{vec}((A \times (B \times X)^T)^T)$$

- A serial operation by nature
- Break down to a sequence of parallel operations

Future of Parallel SPOT

- Contain parallel implementations of all SPOT operators
- Parallelism should be a ‘switch’ in SPOT
- Incorporate load balancing at the highest level

- A SPOT friendly distributed container for data to encapsulate:
  ✓Parallel I/O
  ✓Meta-data - header info, original dimensions
  ✓Shape - current shape, smart reshaping methods

Acknowledgements

- Henryk Modzelewski

SINBAD

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