Parallelization of Belief Propagation Method on Embedded Multicore Processors for Stereo Matching

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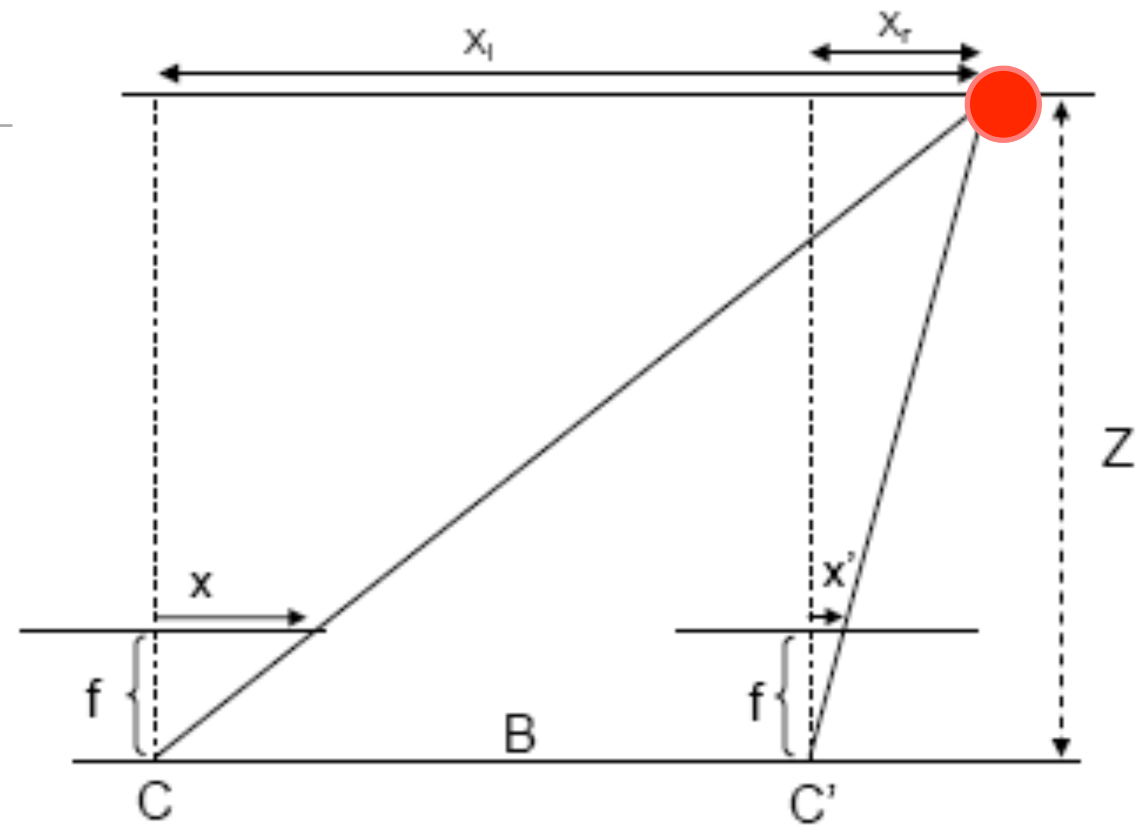
Outline

- Background and motivation
- Belief propagation(BP) algorithm
- Parallelization opportunities
- Experimental results
- Summary

Stereo Vision

- Compute the depth of 3-D objects through matching 2-D images in the same plane
  - Range information of the environment can help the robot to adapt to the real world
- Human acquires two images of the same objects in different sight to find the distance between the man and the object.
- The geometry model of stereo vision describes the relationship between the eyes and the observed object.



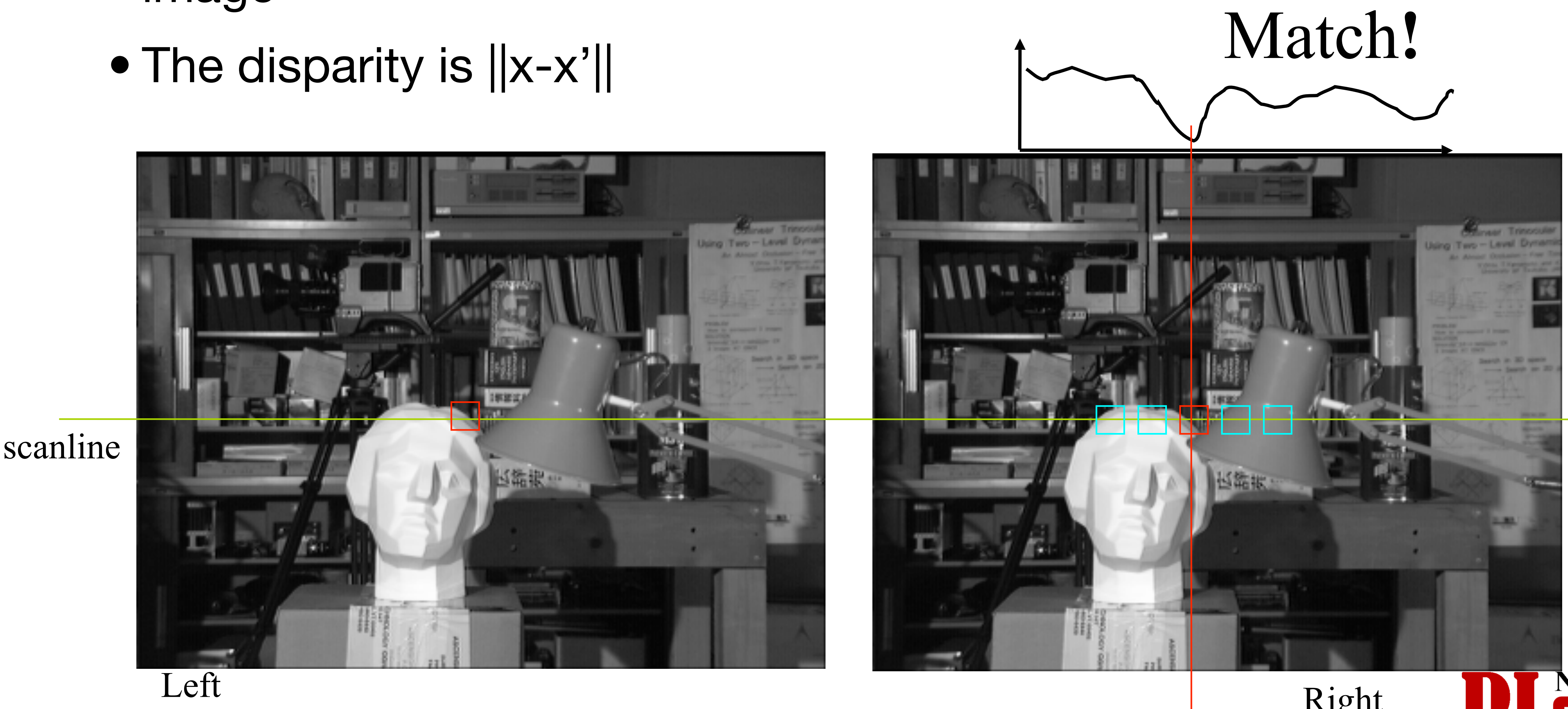
$$\begin{cases} X_l = \frac{x}{f} * Z \\ X_r = \frac{x'}{f} * Z \end{cases}$$

$$X_l - X_r = B$$

$$\Rightarrow Z = \frac{f * B}{(x - x')}$$ (x - x' = disparity)

Introduction to Stereo Matching

- Assume the objects in the two image are in the same scanline
- To find the corespondent points of same objects in the images
  - If the point is in position (x, y) in the left image, (x',y) in the other image
  - The disparity is ||x-x'||

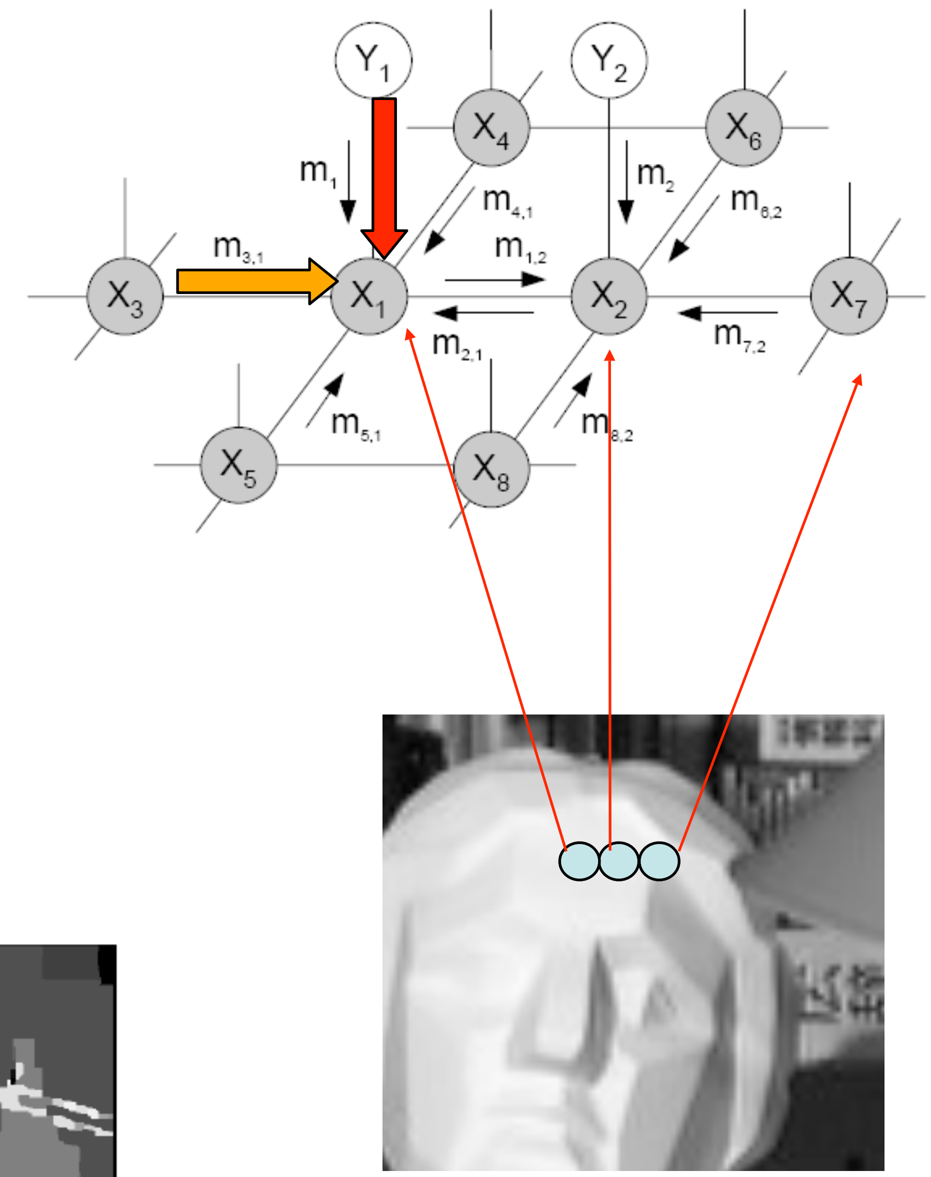


Brief Background: Solving Stereo Matching Problems

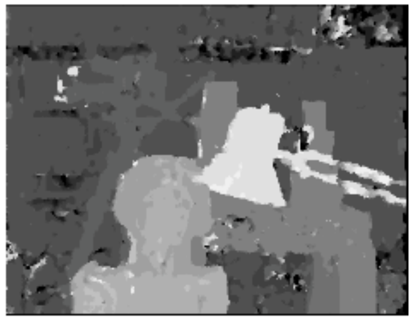
- Two major classes:
  - **Local**
    - Based on correlation, window-based
    - Efficient and suitable for real-time application
    - Have many constraints and results in bad precision
  - **Global**
    - Belief propagation(BP)
    - Retrieving information from the entire image
    - Impressive result, but computation expensive
    - Felzenszwalb proposed a hierarchical method for efficient **BP** method
    - Still not applicable for **real-time** applications

BP: Pixel-labeling Problem

- Pixel-by-pixel
- The goal of labeling is to find minimum of some energy, for stereo problem, it’s the disparity
- Loopy BP, iterative algorithm




0 iter


5 iter


20 iter


100 iter

Hierarchical Belief Propagation

Input: two rectified gray-level pictures // left-side and right side

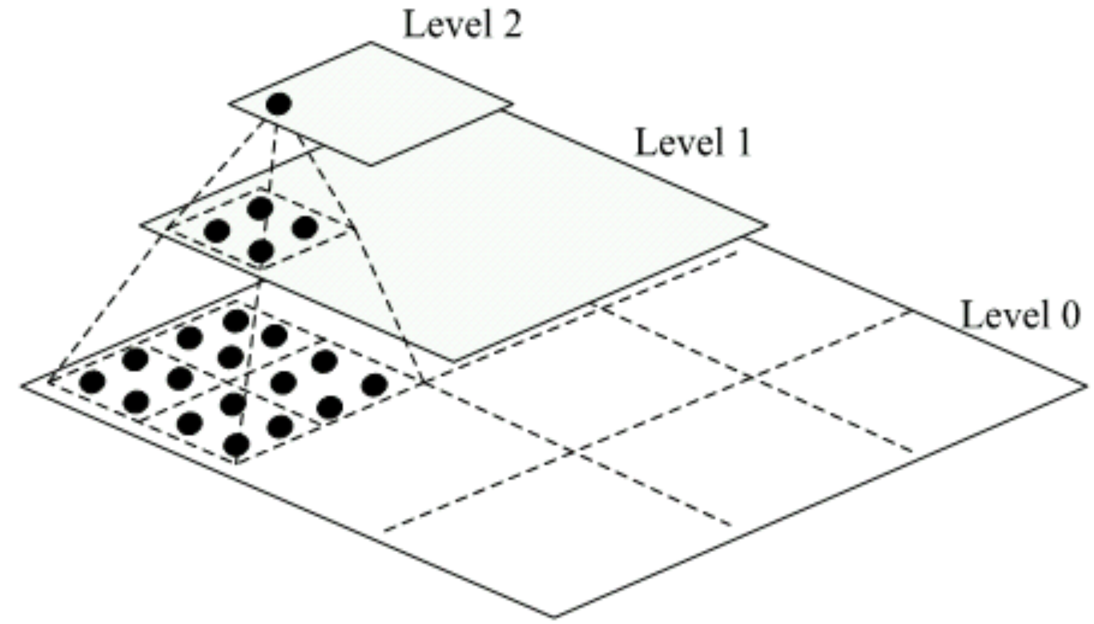
$data^0_{w,h}$ ← difference pixel by pixel between two pictures
// Initial data pyramid

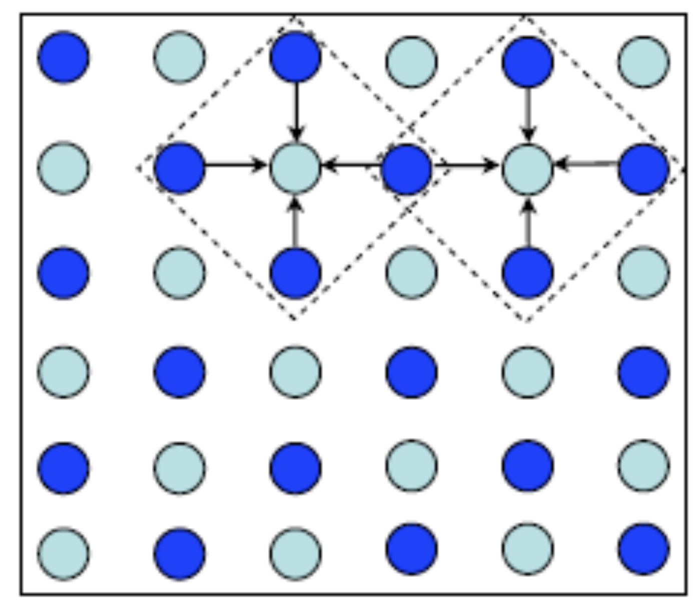
For i ← LEVEL-1 ~ 0 //processing
    If not in top-level
        Initial top-level message layers to 0
    else
        Get message from upper message layers

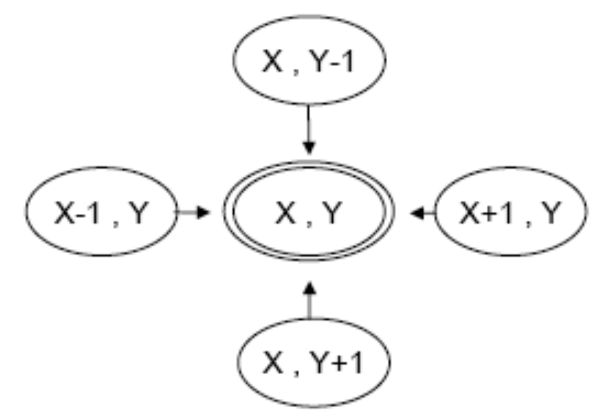
  For t ← 0 ~ ITER-1 //the message deliver iteration
    For y ← 1 ~ height-1
      For x ← (y + t) % 2 ~ width – 1
        Update upward-message of node (x, y)
        Update downward-message of node (x, y)
        Update leftward-message of node (x, y)
        Update rightward-message of node (x, y)
        x=x+2

For y ← 1 ~ height - 1
    For x ← 1 ~ width -1
        accumulate messages delivered by adjacent nodes
        compute disparity of D(x, y)

Output: disparity graph D







Efficient Belief Propagation for Early Vision. Pedro F. Felzenszwalb and Daniel P. Huttenlocher. International Journal of Computer Vision, Vol. 70, No. 1, October 2006.

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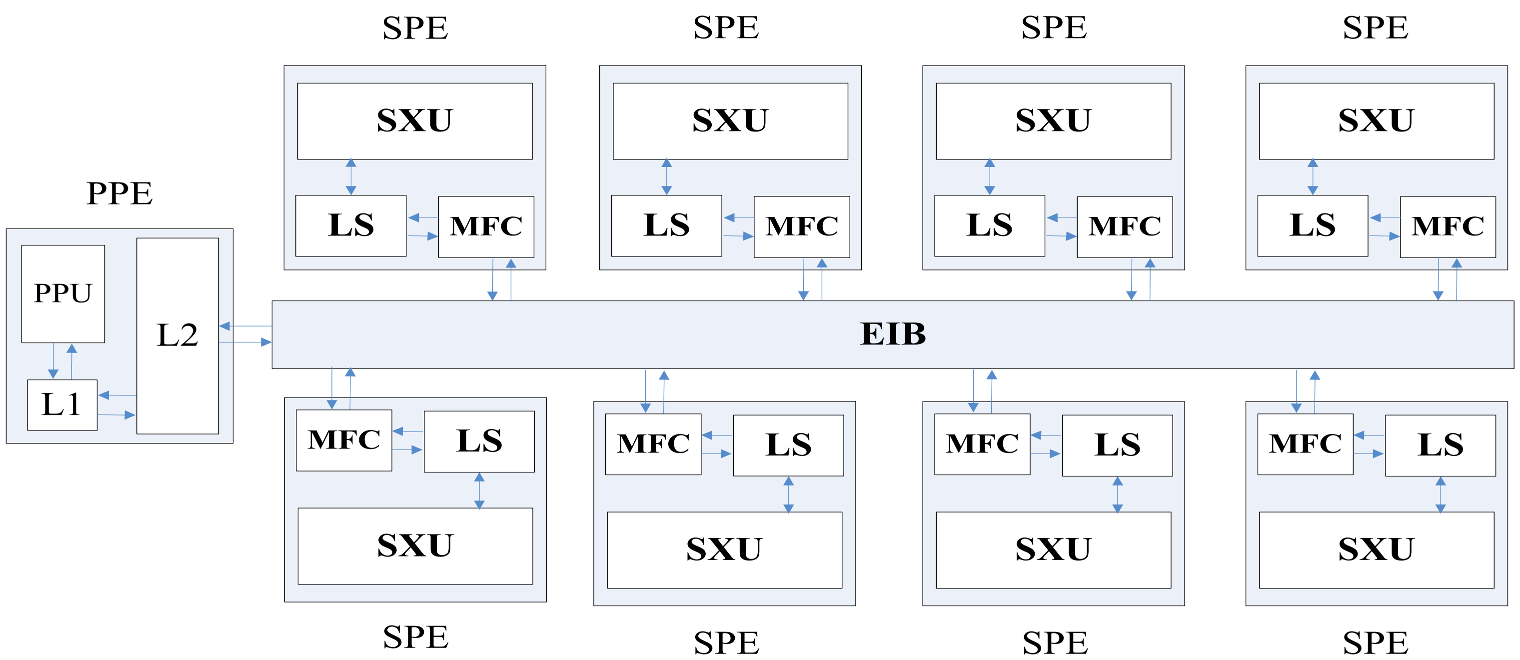
Hardware Support Parallelism of Cell BE

- 1 PPE and 8 SPE
- DMA for data transferring between PPE and SPE
- SIMD instructions in PPE and SPE
  - Exploit data parallelism
  - Intrinsic provided for the programmers



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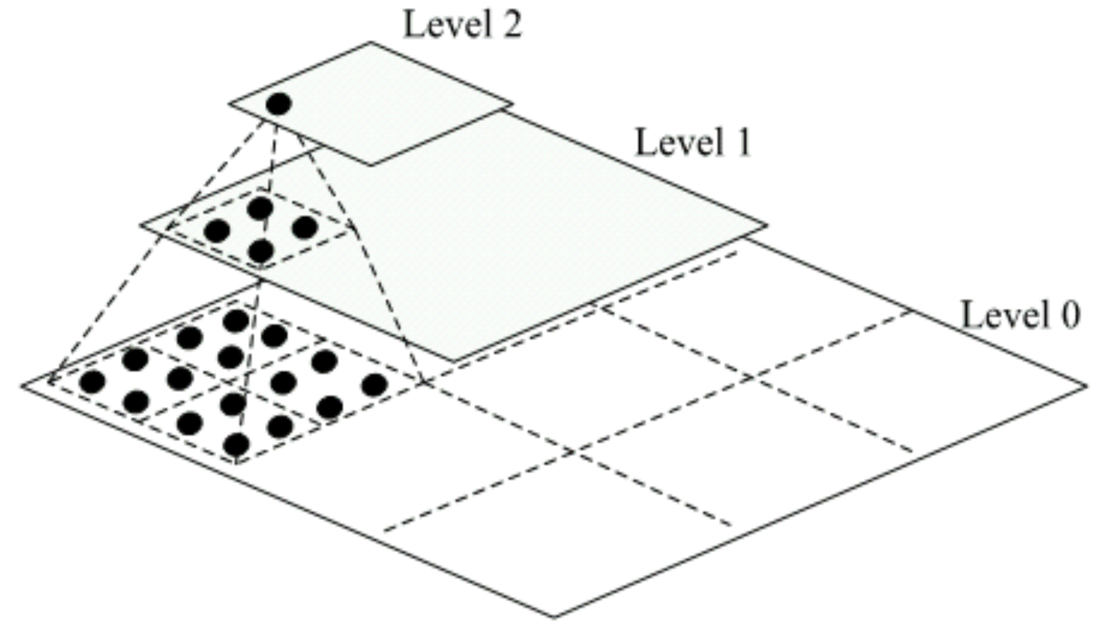

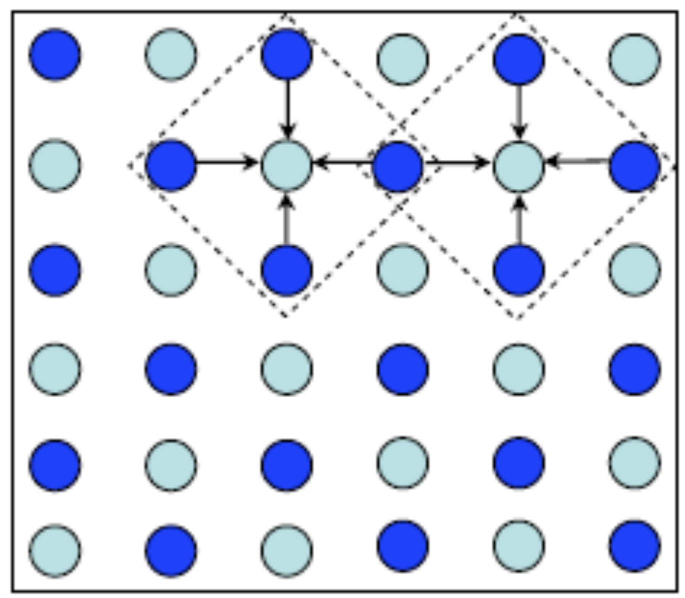

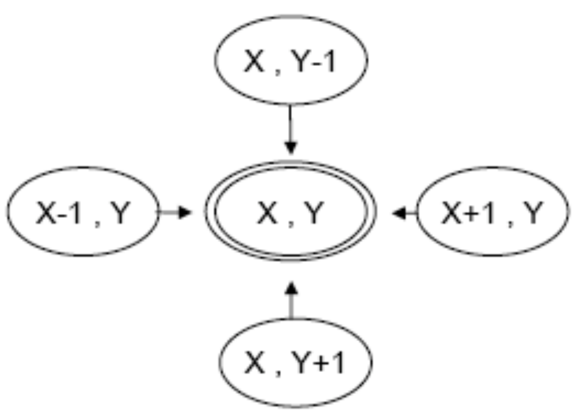

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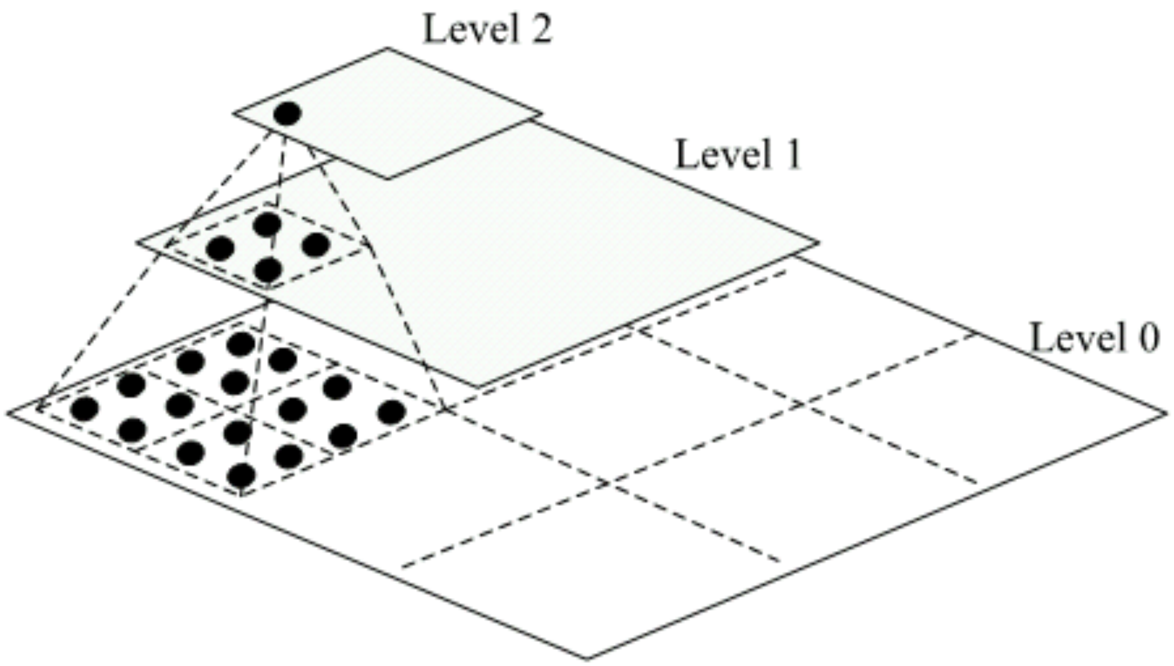
Initialization: Building Data Pyramid



- Constructing the data layer from the input images
- Taking four nodes from the fine-grain layer to build the node to coarser-grain layer
- Considering the generation of each node in the coarsest-grain layer
  - Independent computation
  - **Data parallelism**
- Strategy I:
  - Building each sub data pyramid in parallel
  - Executing on SPEs

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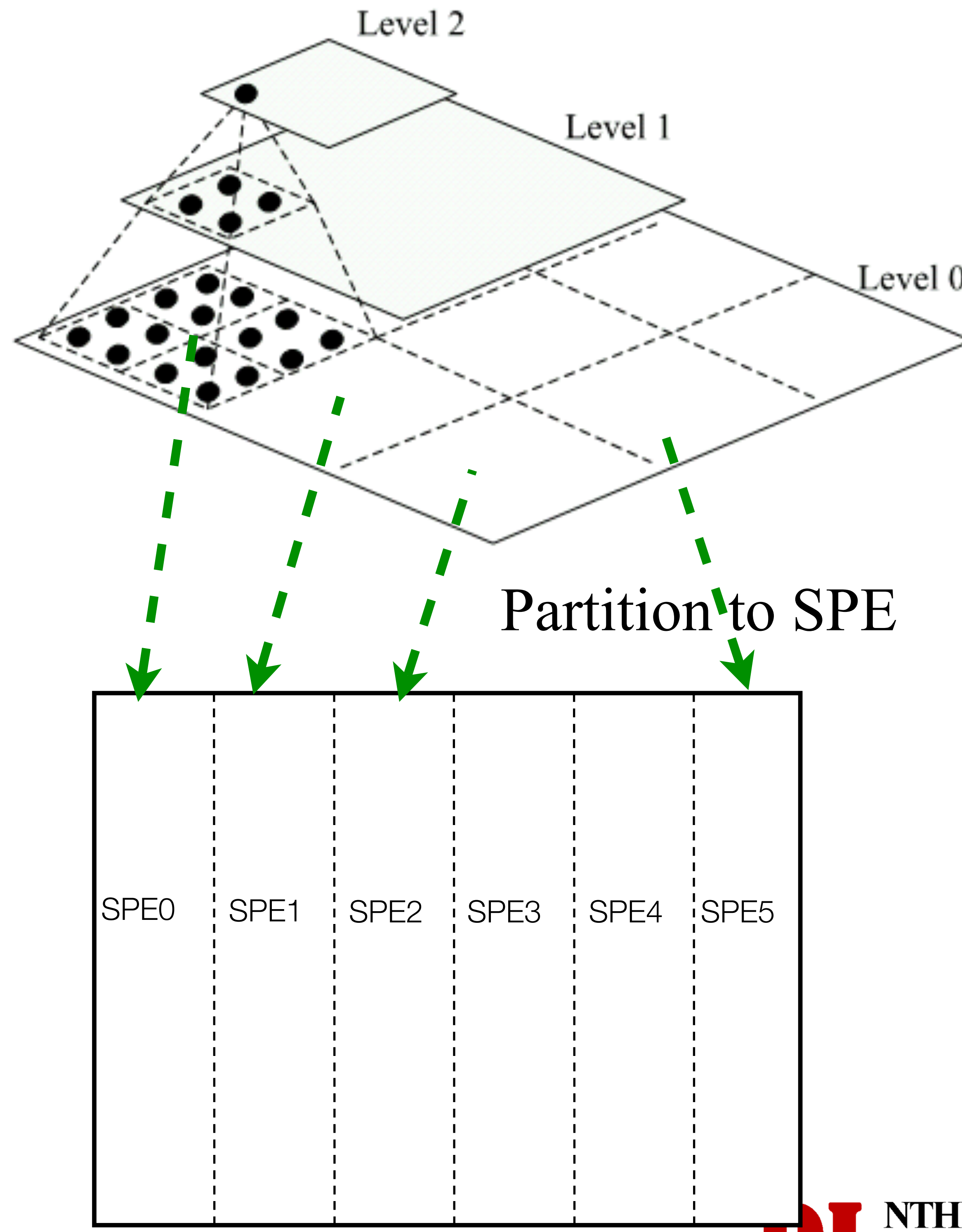
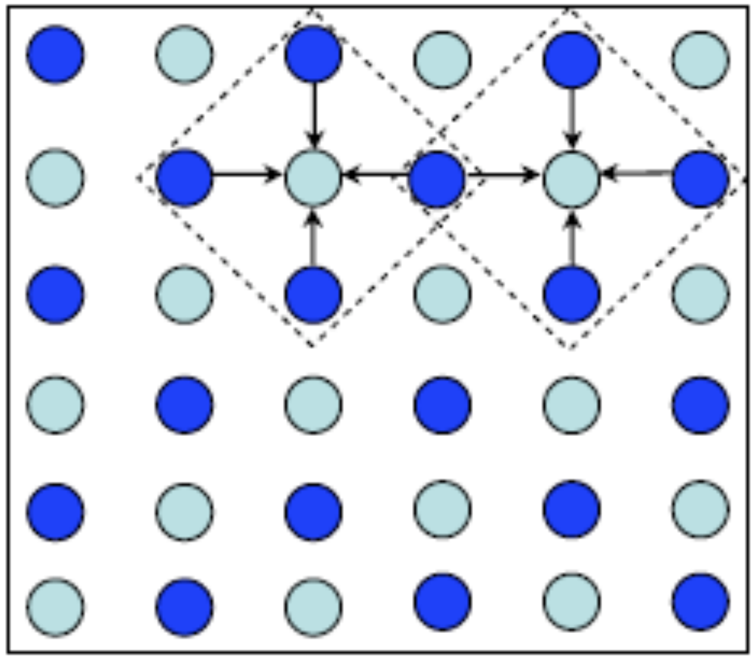
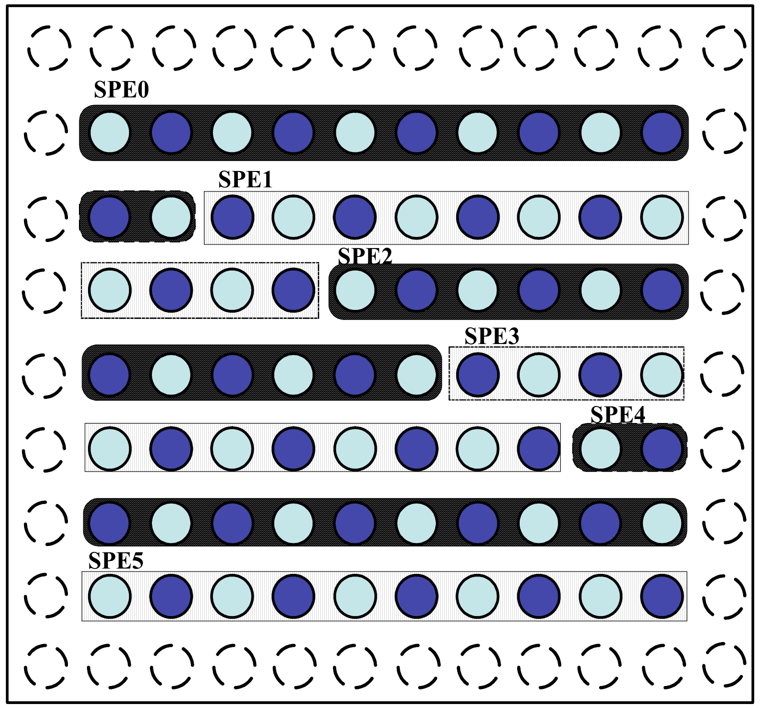


Labeling, Message Updating
Finalizing, Calculating the Disparity





- 90% of the computation workload
- Iteratively updating
- Message updating
  - Required the result(message) of the last iteration from the adjacent nodes
  - To update the message to the adjacent nodes
- The updating processes for each node, the four directions, are each iteration is independent
- Strategies:
  - Updating the message in each direction in the SPEs -> bad data reuse
  - Grouping the nodes for each SPE

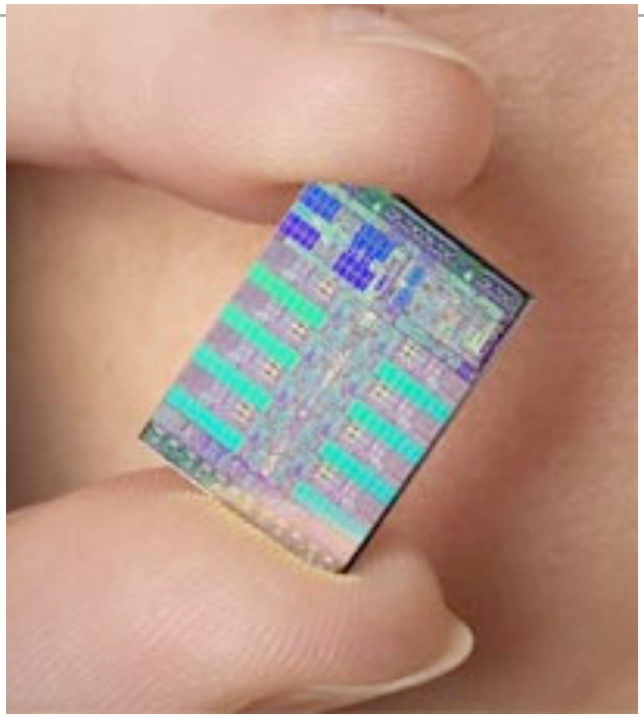
Exploiting Hardware Features

- SIMD
  - Process four data elements simultaneously
- Using DMA by multi-buffering
  - To overlap communication and computation
  - Hiding the data transferring overhead
- Configuring the data layout
  - Aligned to 16 bytes
  - For DMA transferring
  - For SIMD vector operations

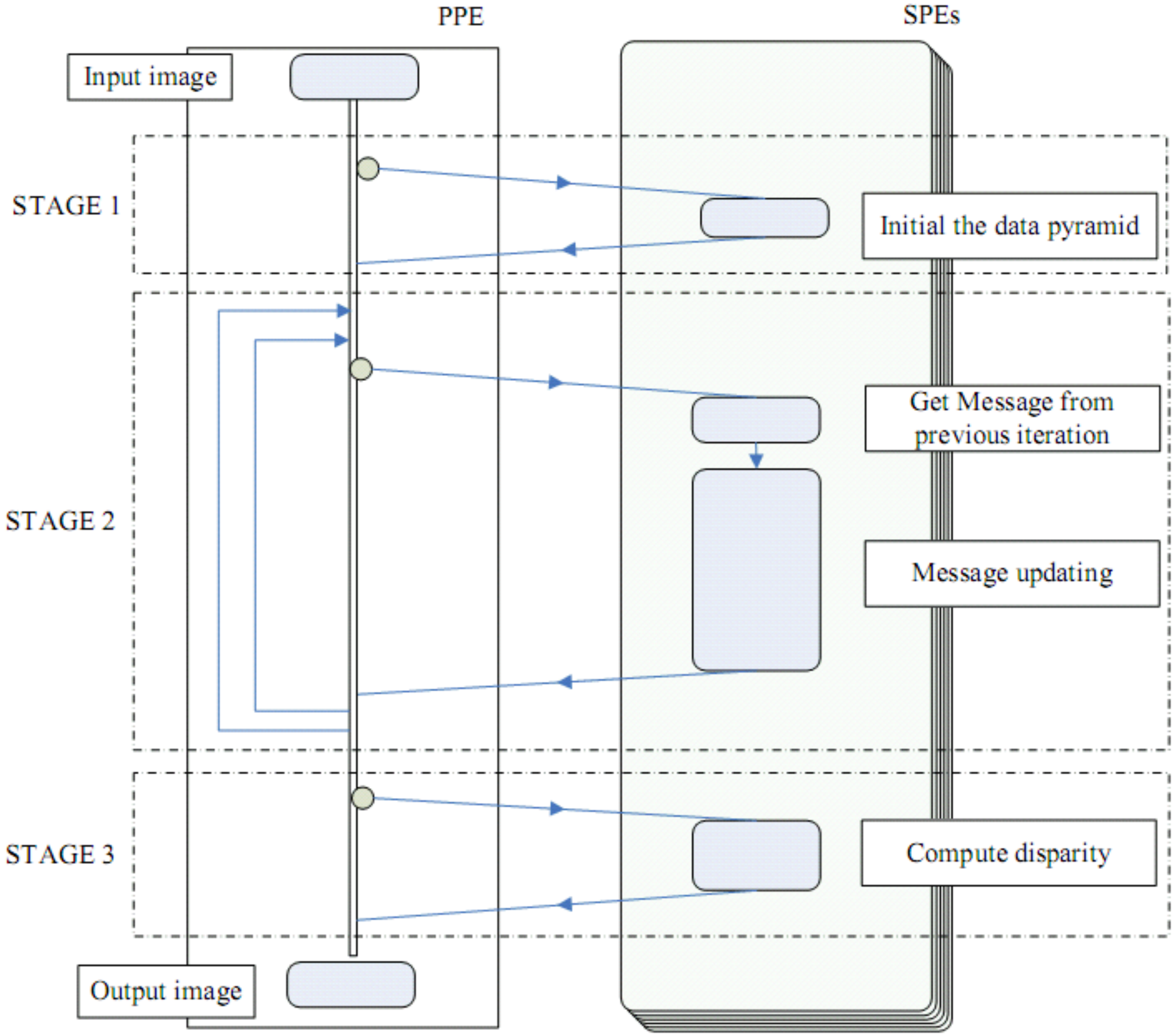
```
floatVec f __attribute__ ((aligned (16)));
vector float *vc = (vector float *)&(f.vec[0]);;
vector float fconst = (vector float ) { 1.0 , 1.0 , 1.0 , 1.0 } ;
vector float a0, a1, a2, a3;
...
/* f i s seperated by vc [0] , vc [1] , vc [2] , vc [ 3] */
a0 = spu add( fconst , vc [0] ) ;
a1 = spu add( fconst , vc [1] ) ;
a2 = spu add( fconst , vc [2] ) ;
a3 = spu add( fconst , vc [3] ) ;
```

Experiment Environment

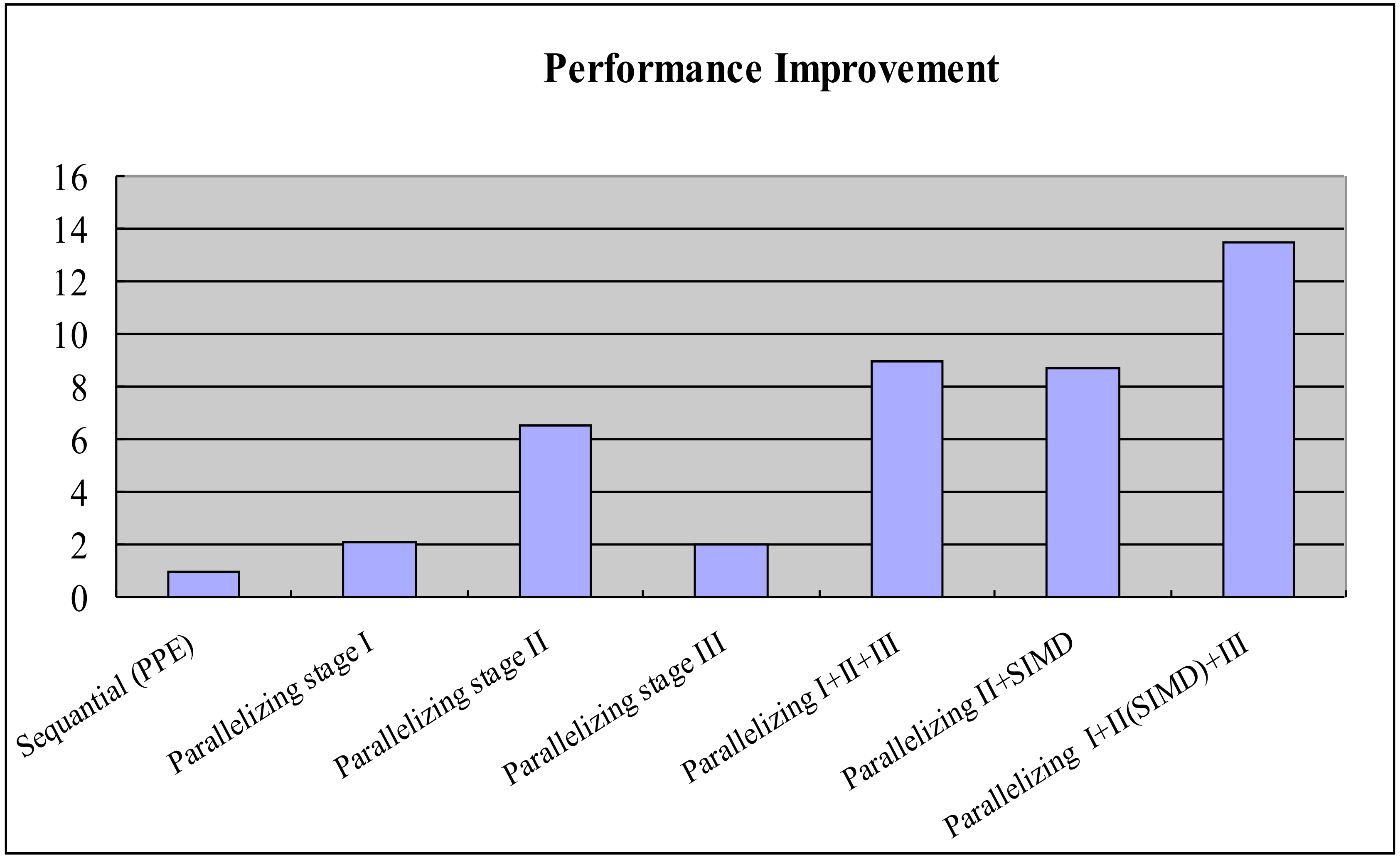
- CPU
  - Cell B.E. processor
  - One 64-bit PowerPC architecture core (PPE)
  - 8SPEs, but only 6 SPEs accessible
- Memory
  - 256 MB XDR DRAM
- OS
  - Linux (Fedora 6)
  - Kernel 2.6.25.4
- Cell programming environment
  - gcc 4.1.1-57 for PPU
  - gcc 4.1.1-107 for SPE
  - binutils-2.17.50-32 for PPU
  - binutils-2.17.50-33 for SPE
  - libspe 2.1
  - newlib 1.5.0-7 for SPE
- Input images of 384X288
  - **5** iterations, **6** disparity levels

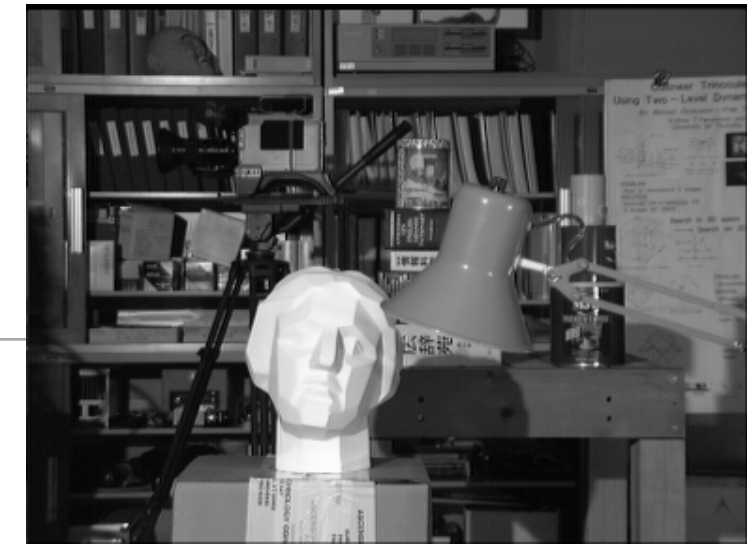


The Execution Flow on CellBE



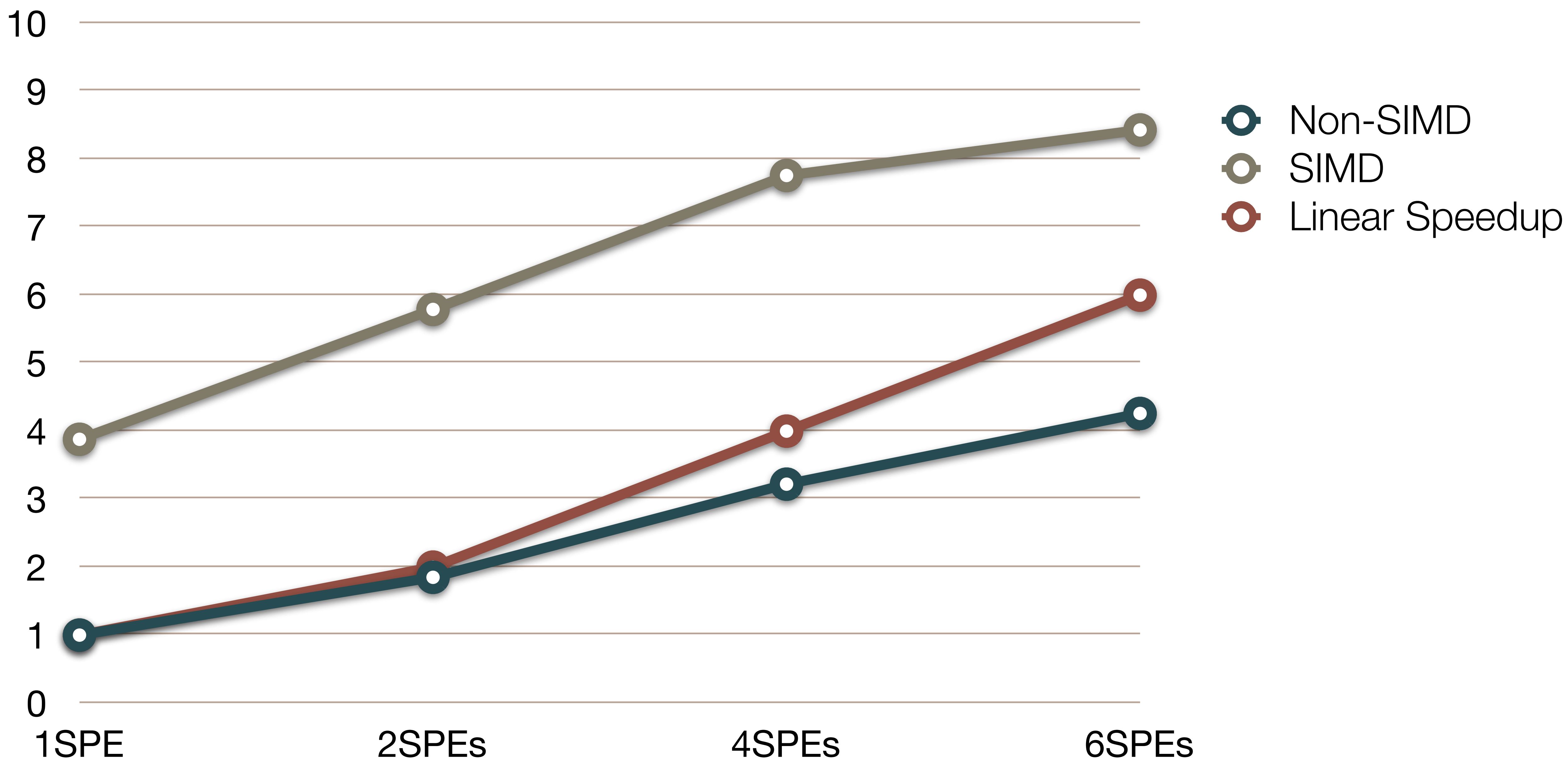
Performance Results





	Sequential	Sequential	Parallelized BP
Platform	3G Pentium 4	PPE on Cell BE	Cell BE
Performance(seconds)	1.195	2.34	0.175
Frame Per Second	0.84	0.43	5.71

Performance Scaling



Conclusion

- Analyzig and examing the parallelization of a belief propagation algorithm on the multicore processors
- Exploiting the opportunities for real-time application
- With careful analysis and parallelizing, the implementation is able to produce a good result

Thank you!

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