

# Non-Uniform Hierarchical Pyramid Stereo for Large Images

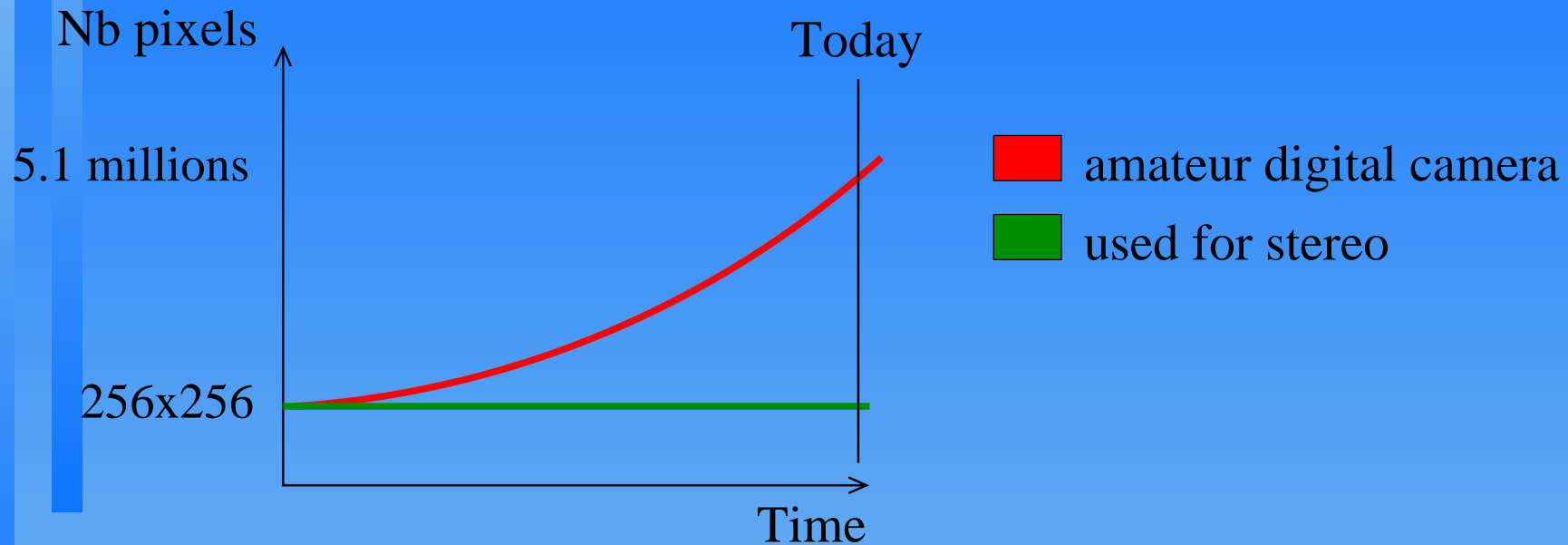
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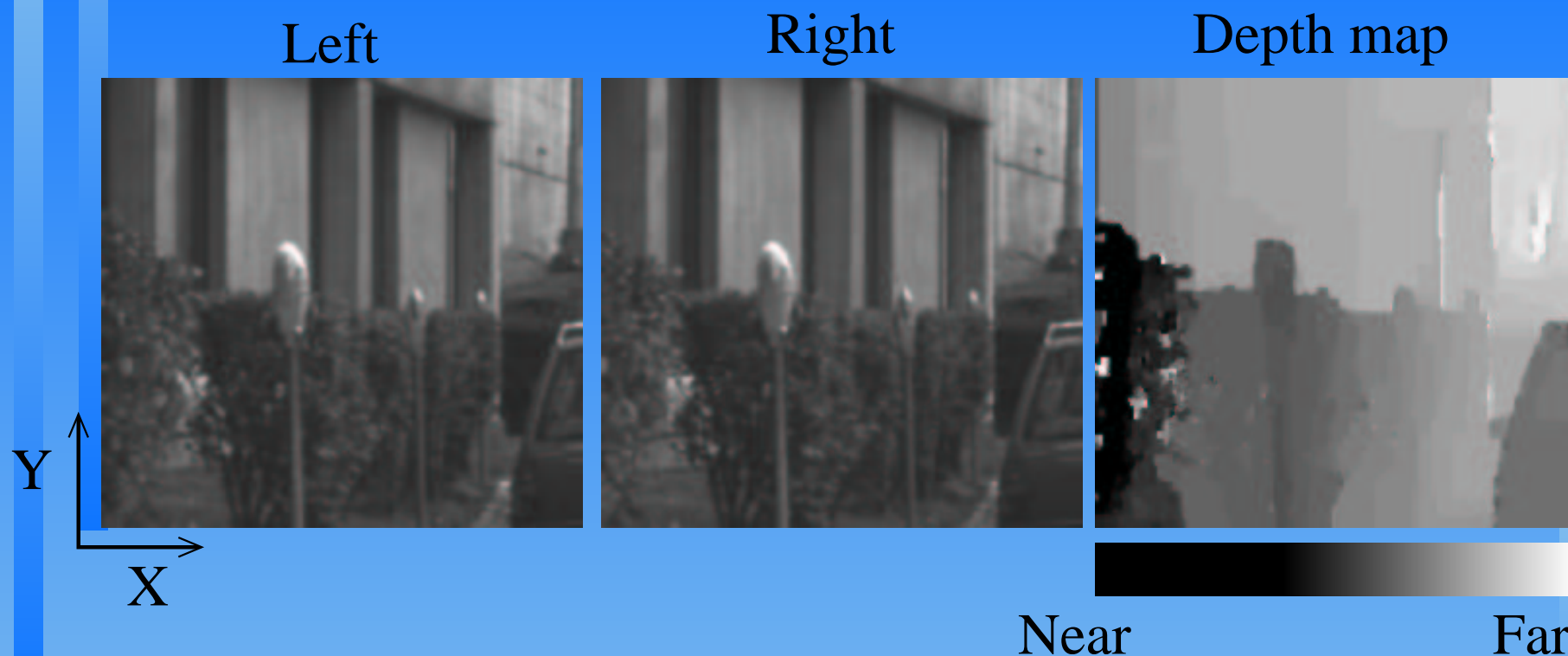
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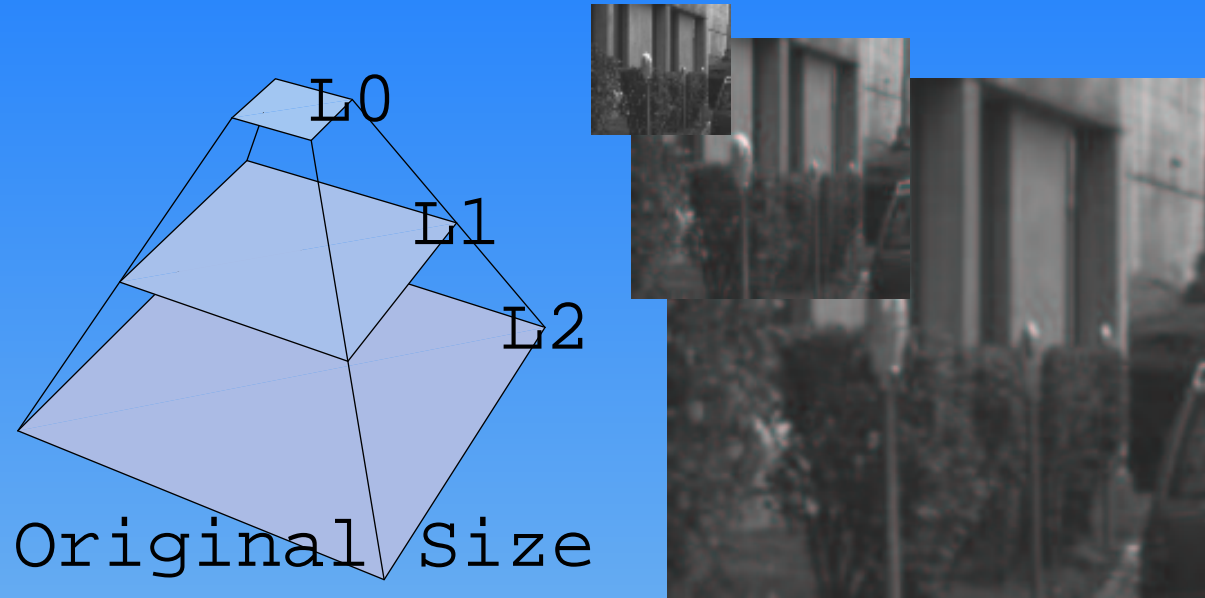
- Introduction.
- Classical pyramids.
- Error classification.
- Dealing with errors.
- The algorithm.
- Experimental results.
- Conclusion.



- Pyramidal schemes have been introduced to deal with high resolution images.
- Pyramidal schemes suffer from error propagation.
- We want to minimize error propagation between pyramid levels.

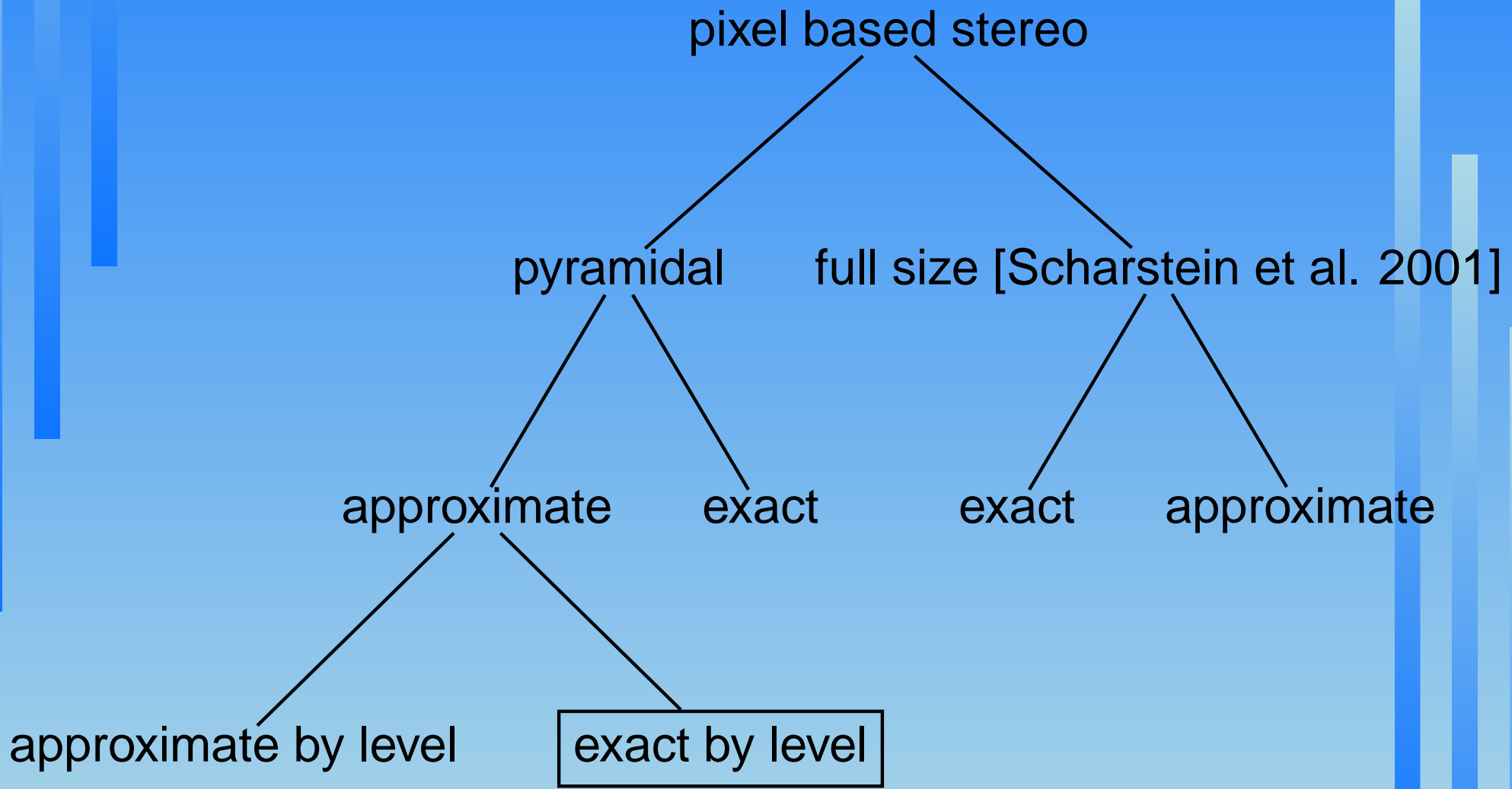


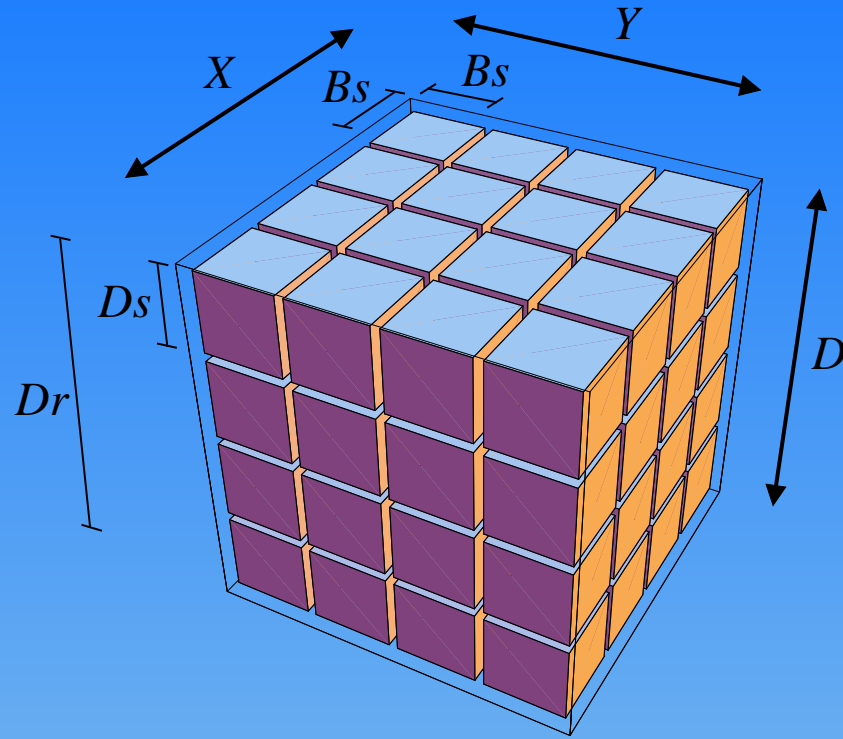
- For each pixel in the left image we try to find the corresponding pixel in the right image.
- The resulting displacement for that pixel (disparity) represents the distance between the object and the reference camera.



- $L0$  is solved first.
- $L1$  is then solved using the result of  $L0$  as an initialization.
- $L2$  is then solved using the result of  $L1$  as an initialization.
- There can be more than 3 levels.

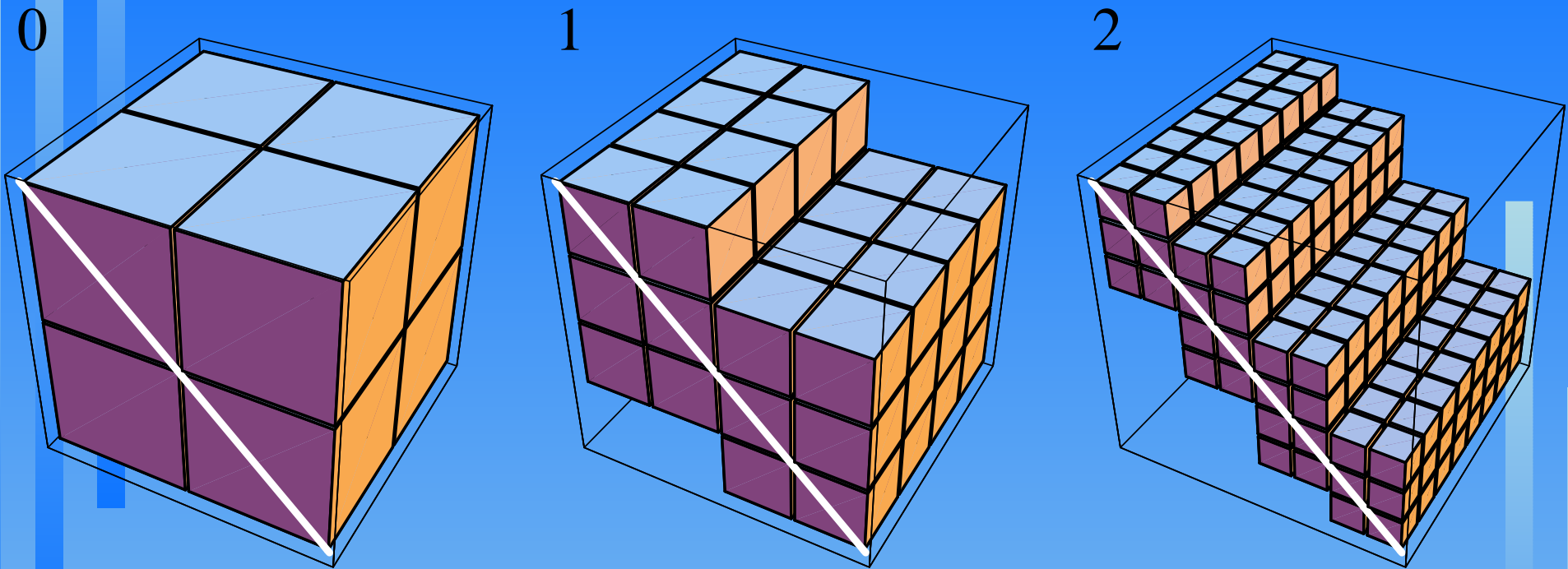
Algorithm	Smoothing term	Solution
direct search	no smoothing	exact
dynamic programming	epipolar line	exact
maximum flow	convex	exact
...	...	...
graph cut	non-convex (robust)	approximate
...	...	...



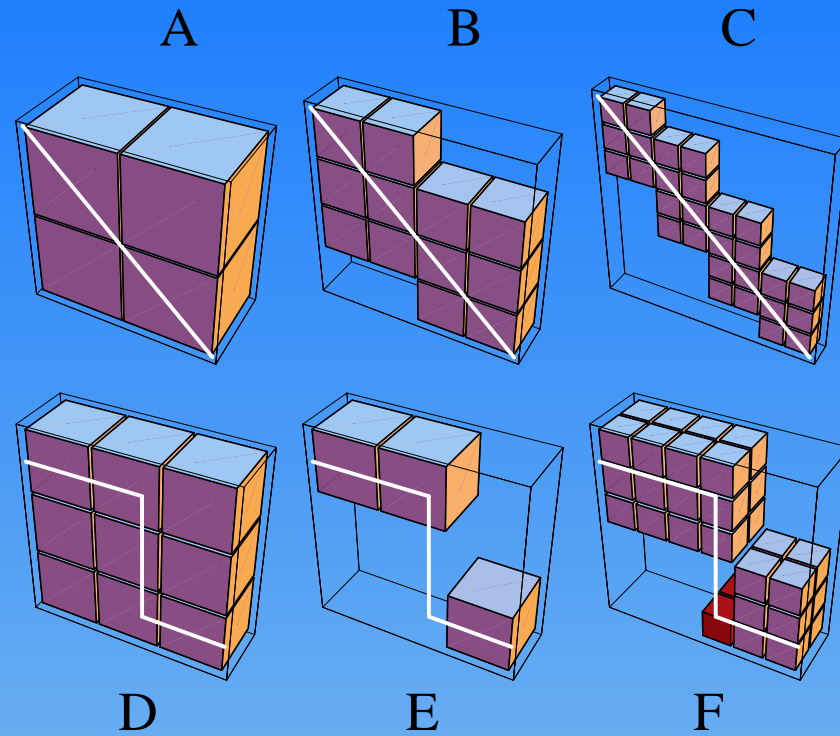


- $(X, Y)$  plane is the disparity map with block size  $B_s$ .
- Axis  $D$  is the disparity to assign over a range  $D_r$  and disparity step  $D_s$ .





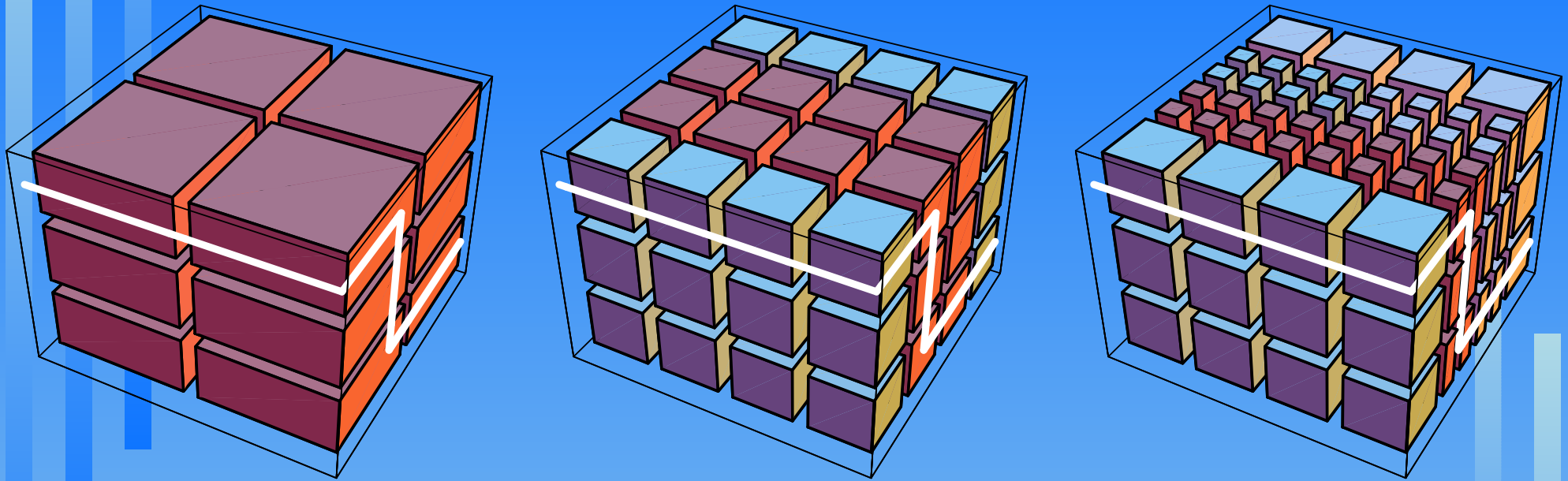
- Simultaneously increase the spatial and disparity resolution while reducing the disparity range.
- level 0 is over the full disparity range (absolute mode).
- level 1,2 is over an interval around the previous solution (relative mode).



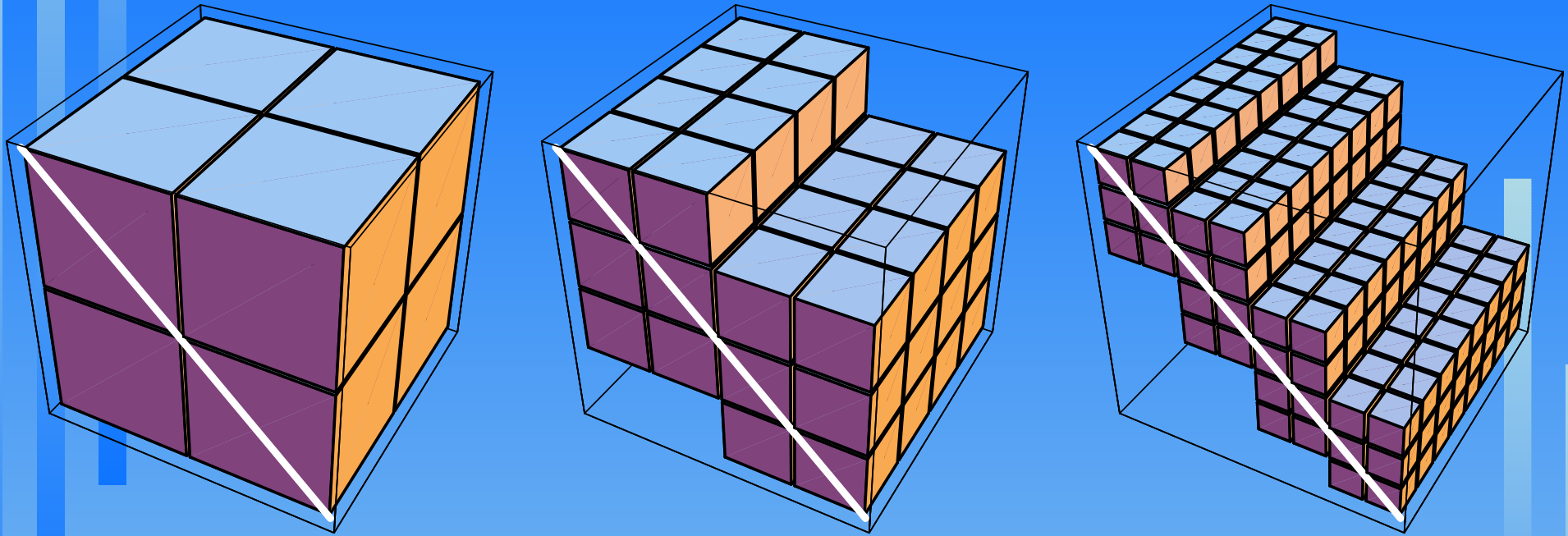
- Two kinds of error:

(A-C) Smooth surface error (can be recovered by classic pyramid).

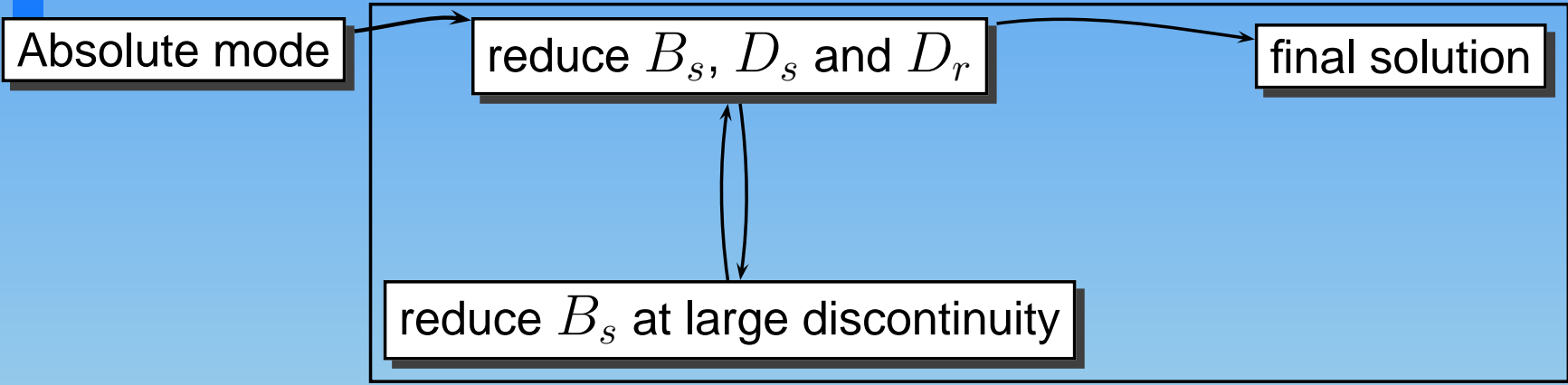
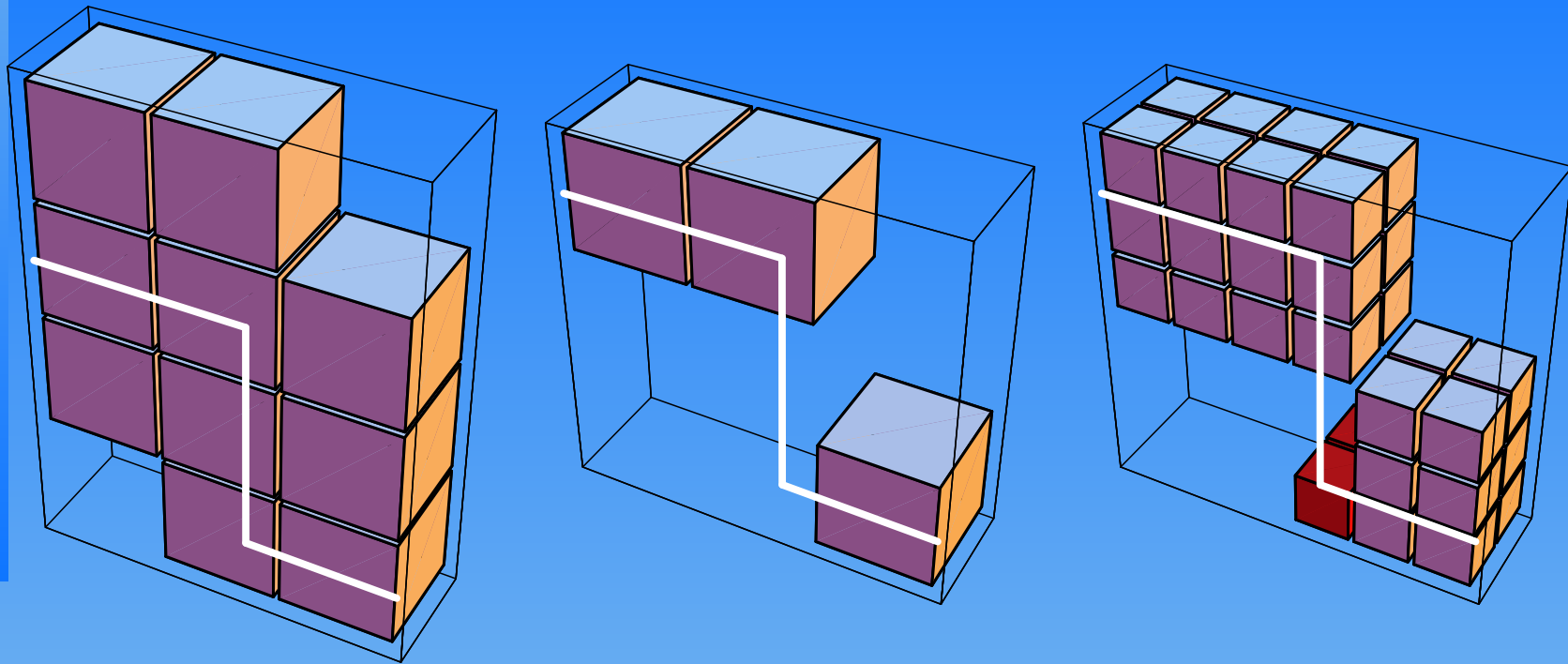
(D-F) Discontinuity localization error (cannot be recovered by classic pyramid).

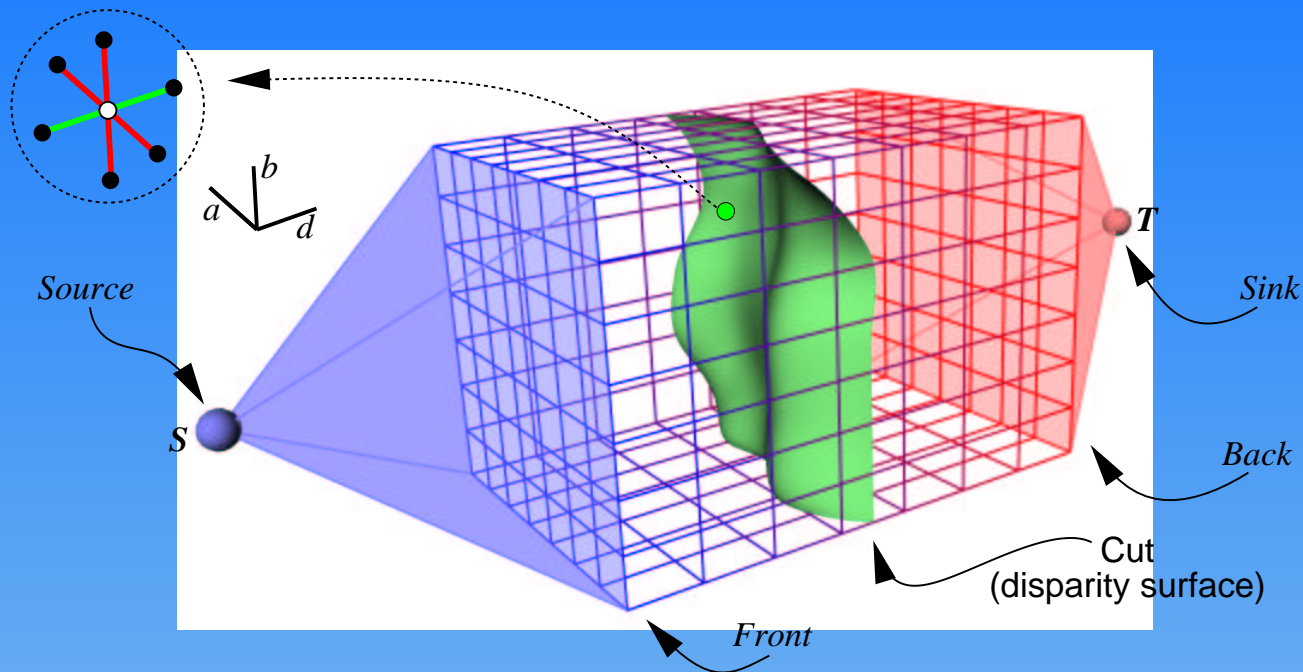


- Increase spatial resolution at large discontinuities.
- A depth discontinuity is large if it is greater than a threshold.
- Keep subdividing until border localization is at one pixel resolution.
- The increase of the solution space is small.



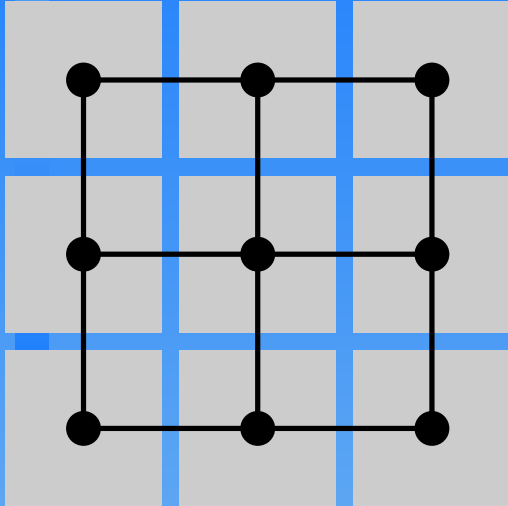
- Increase spatial and disparity resolutions simultaneously.
- Use relative mode to keep solution space under control.
- Prevent large discontinuity error from reappearing.



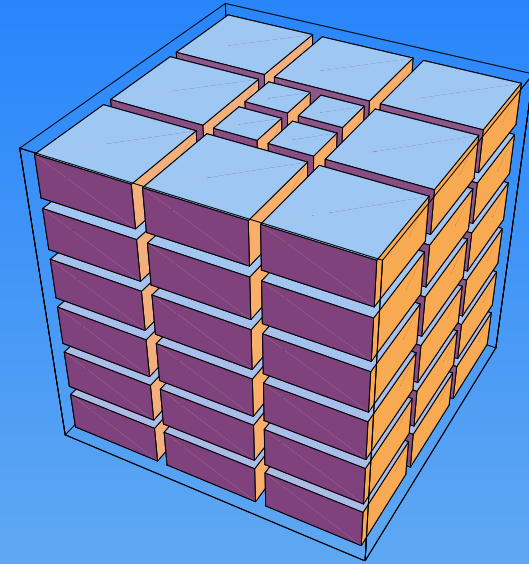
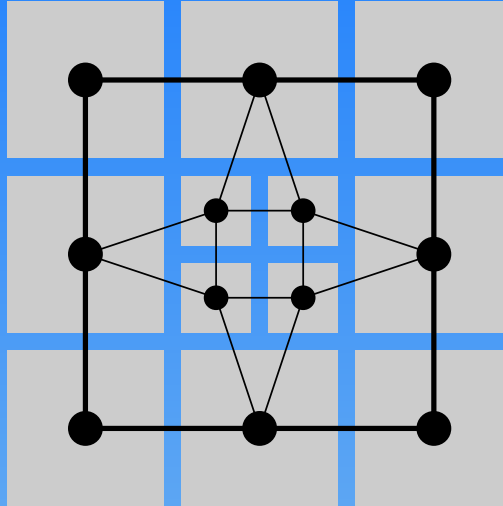


- Disparity map in the solution space represented as a cut in a graph.
- Finds sharp depth discontinuity.
- Features an arbitrary neighborhood structure independent of the epipolar constraint.

Coarse pixel grid



Non Uniform grid

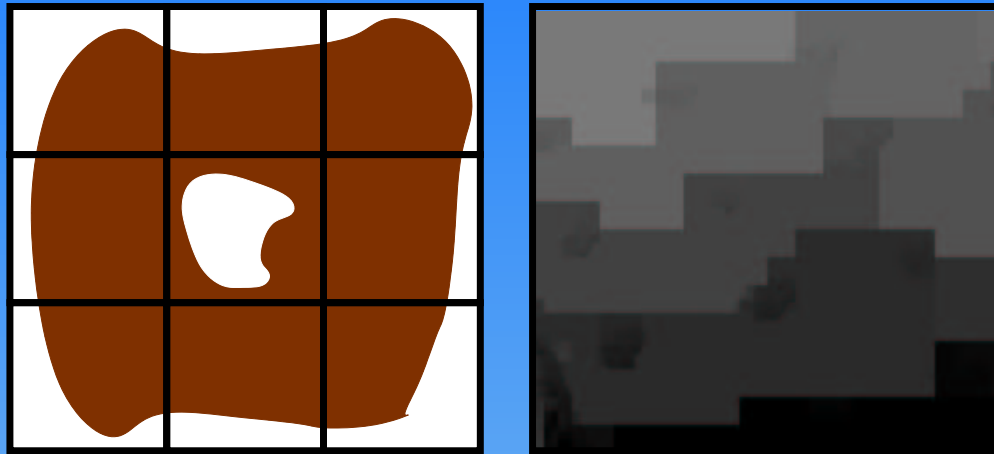


- Smoothing edge have a “cost” proportional to the contact surface.
- Regularity of the graph allows an memory efficient implementation.

Our goal is to demonstrate the usefulness of Non-Uniform decomposition.

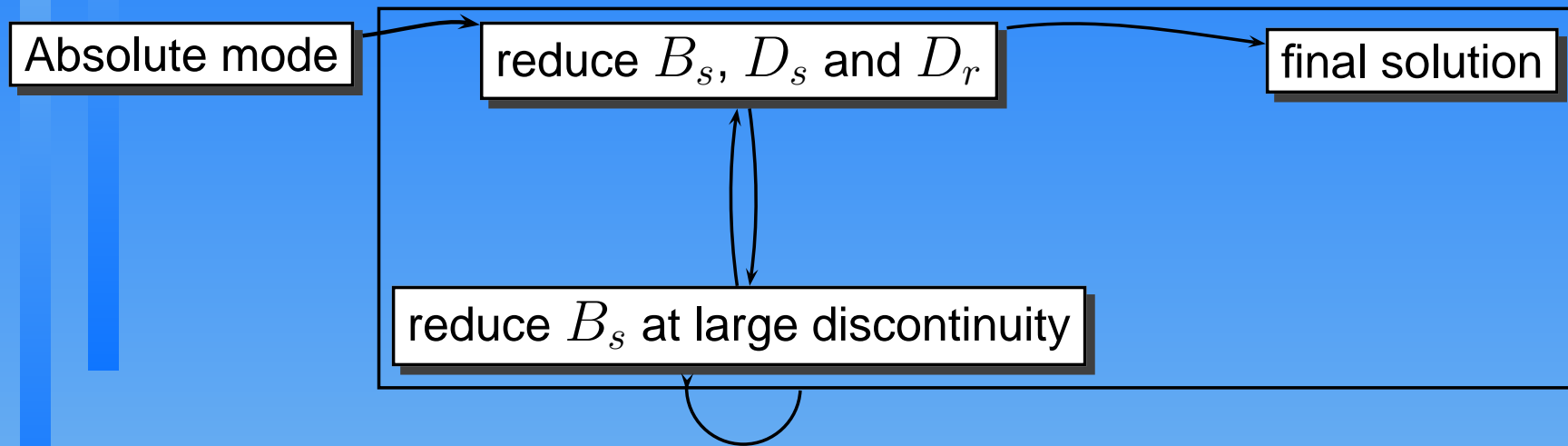
- A simple cost function based on block matching and SSD is used.
- There is no explicit modeling of occlusion.
- There is no adaptive smoothing.



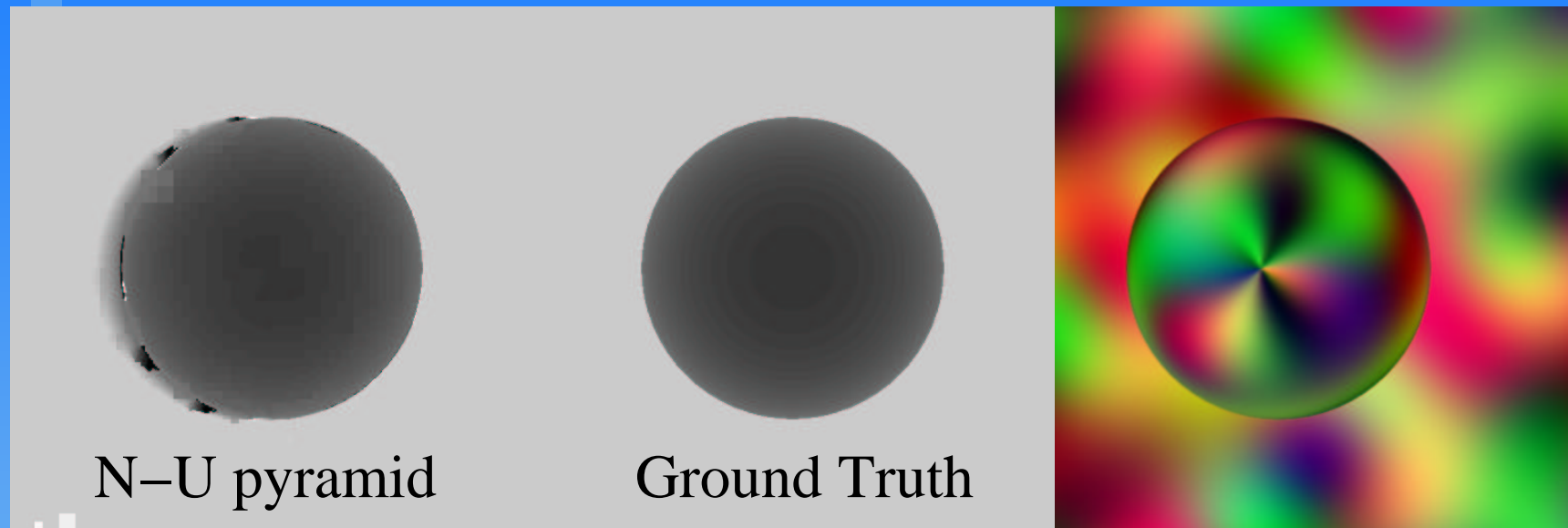


Too coarse initial grid or too large threshold value can have a significant impact on the quality of the final solution.

- missing large depth discontinuities.
- pixelized smooth surfaces.



- Not all depth discontinuity errors are removed in the absolute phase.
- During the relative phase, extra iterations could be needed to get rid of them.

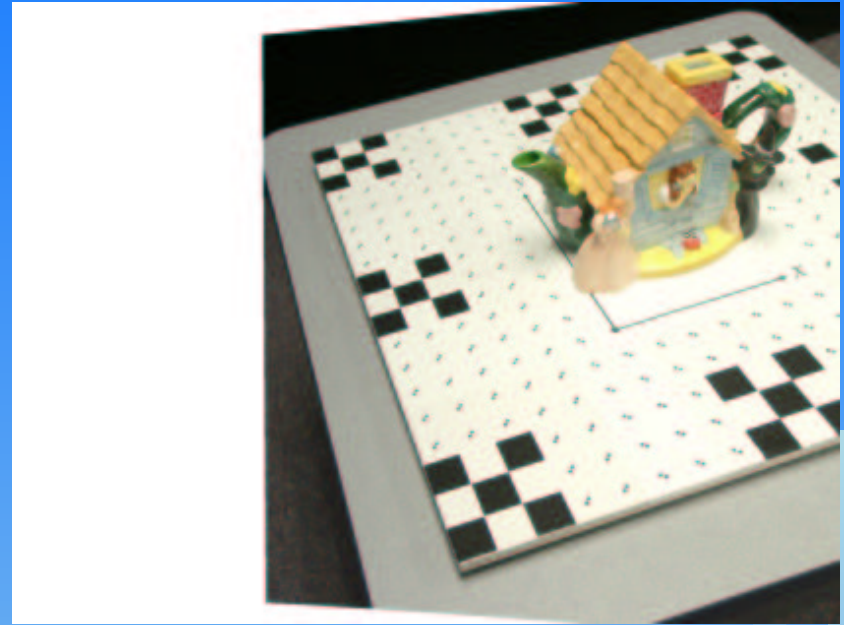


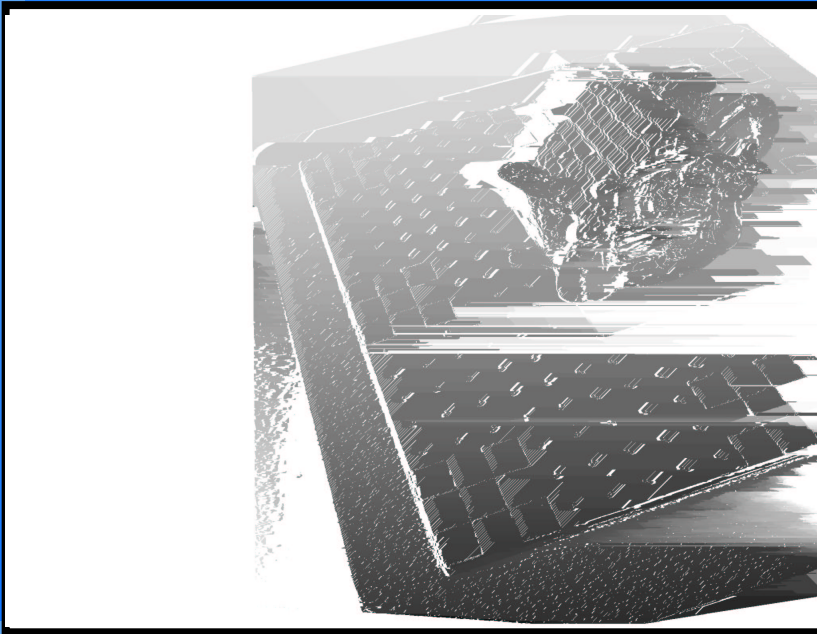
- Resolution  $512 \times 512$  and 64 disparity steps (17 millions nodes ).
- Running time is about 10 sec on AMD Athlon 1.4Ghz.
- 200 000 elementary operations (100 million for the full size problem solved by Max-flow).



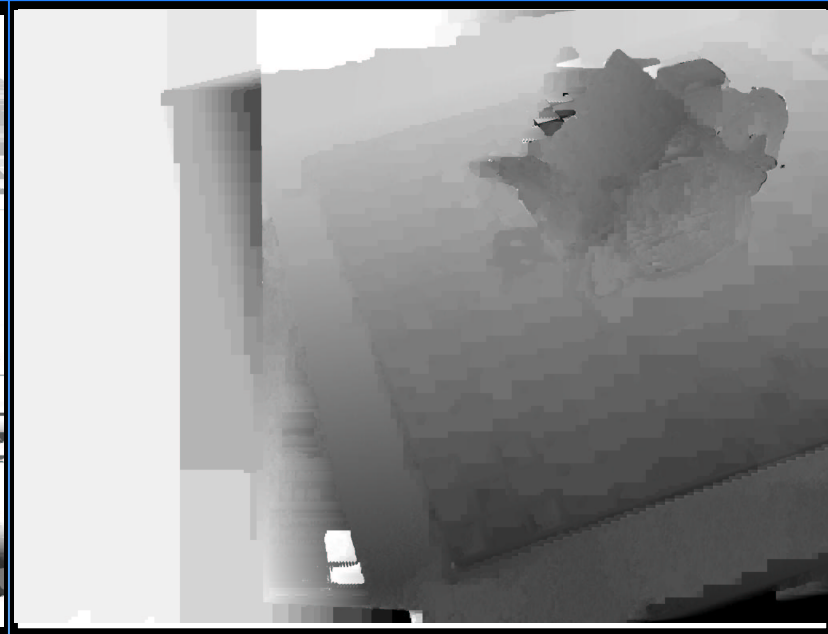
- Non-Uniform and Uniform have the same running time.
- MRSS [C.Sun, 99] uses Non-Uniform decomposition in order to speed-up computation but does not model large discontinuities.

- Courtesy of Jean-Yves Bouguet.
- Resolution  $2048 \times 1536$ .
- 400 disparity step.
- $400^{3145728}$  possible configuration.
- Graph size over a billion nodes.
- Important occlusion zones.
- Specular components.
- Texture less slanted surface.



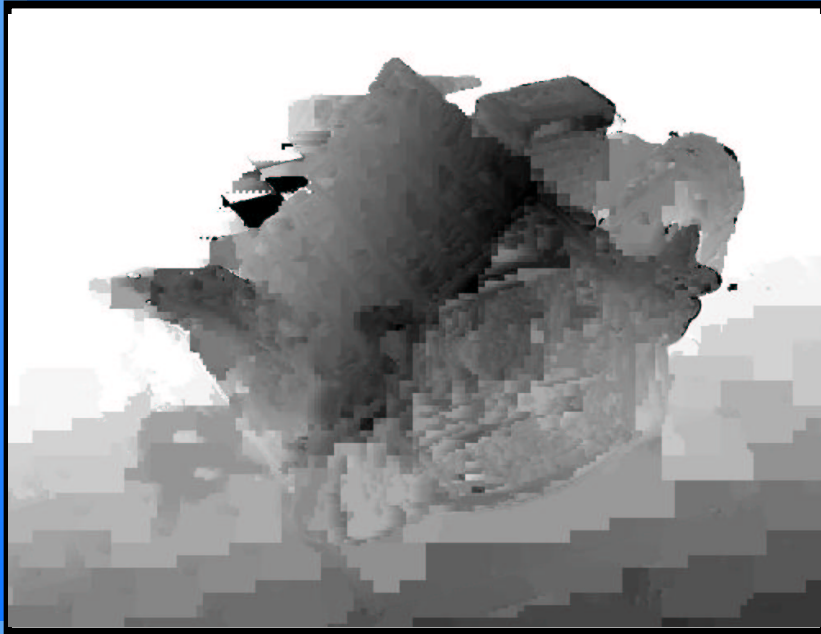


Dynamic Programming

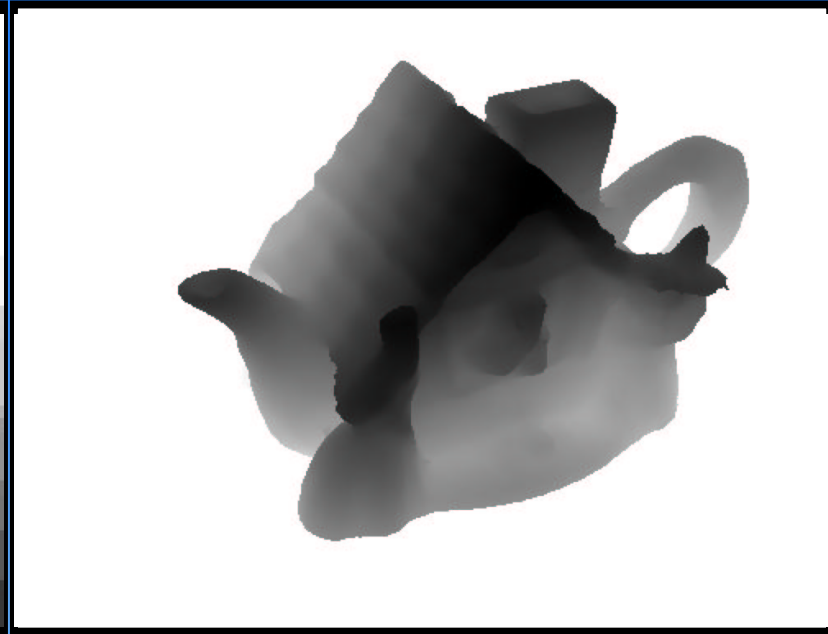


N-U Pyramid

- Cox algorithm was used for the dynamic programming.



N-U Pyramid



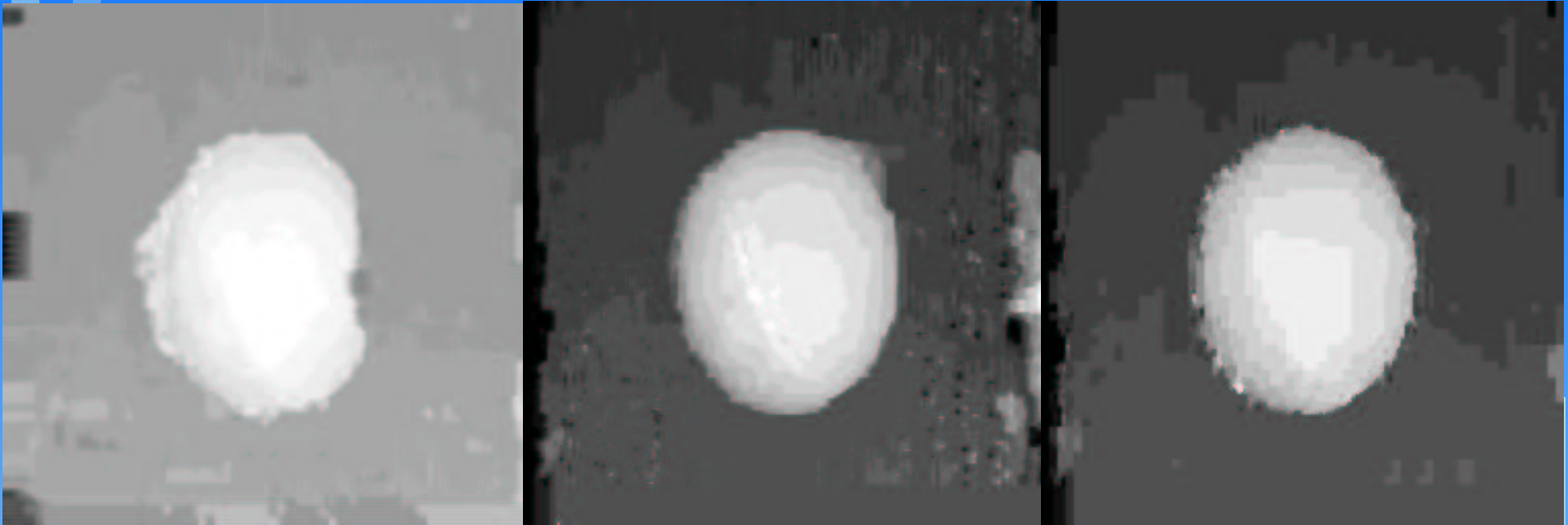
Ground Truth

- Ground Truth is obtained by structured light (Jean-Yves Bouguet).

- Courtesy of Bill Hoff.
- Resolution of  $256 \times 256$ .
- 18 disparity step.
- Highly textured.
- Exposure variation between images.
- Sharp contours.







MRRS

Max-Flow

N-U Pyramid

- 9.4 million elementary operations for Max-flow.
- .57 million elementary operations for Non-Uniform pyramid.

- A pyramid scheme that alternates the computational effort between border localization and surface smoothness.
  - Stability and efficiency of pyramid scheme.
  - Border localization typical of exact approaches.
- We extend Maximum-flow to allow solving very large problems efficiently while preserving the quality of the solution.

- A pyramid scheme that is guaranteed to find the exact solution of the original full size problem.
- Adaptive and automatic determination of the smoothing factor and threshold value.