GPU Point List Generation through Histogram Pyramids

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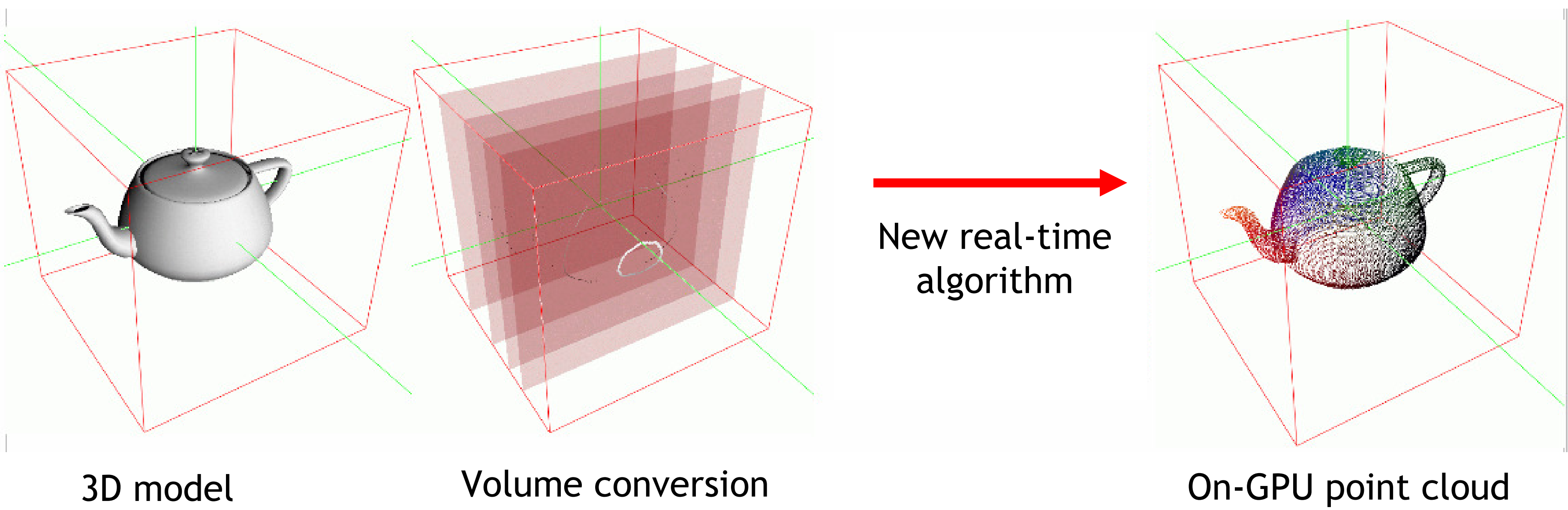
Agenda

- Overall task
- Problems
- Solution principle
- Algorithm: Discriminator
- Algorithm: HistoPyramid Builder
- Algorithm: PointList Builder
- Applications
- Future Directions, Conclusion
- (Extra: Feature Detection, Geometry Generation, 3D Volume, QuadTree)

Overall task

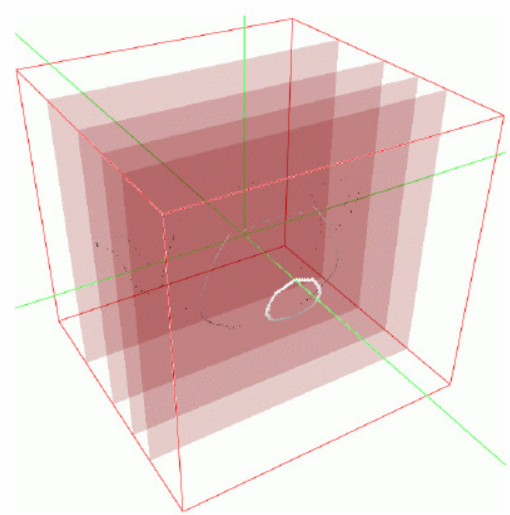
- Decompose a 3D model into a point cloud
- Vertices don't suffice, require minimum sampling density
- Make GPU render 3D model into 3D volume slices
- Problem: 256^3 points, many unfilled – find active ones !



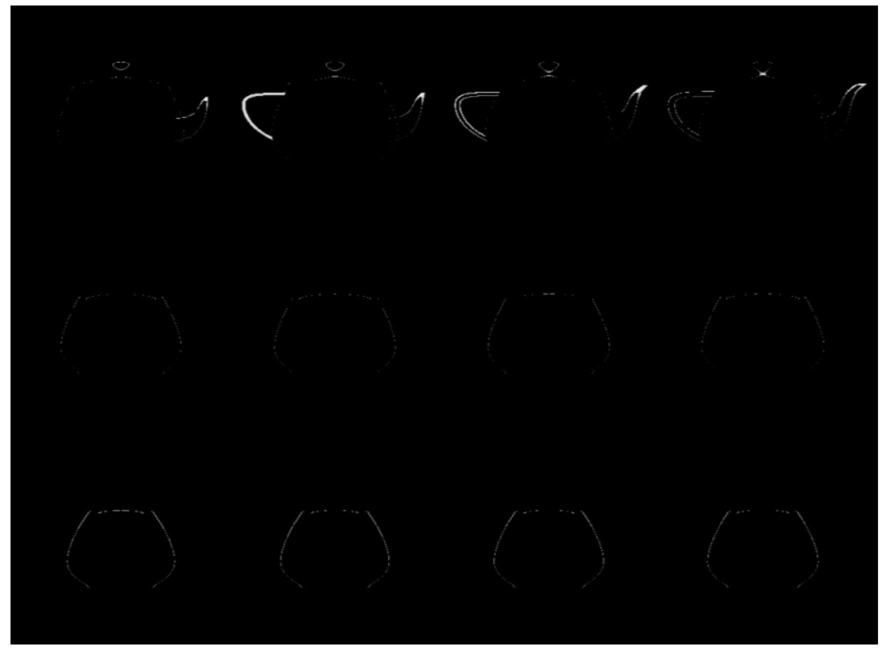
http://tinyurl.com/y5d8sh

Side problem: 3D to 2D mapping

- NVidia GPUs cannot render into 3D volume textures.
- **Solution: Create a 2D mapping scheme for 3D volume.**



3D Volume

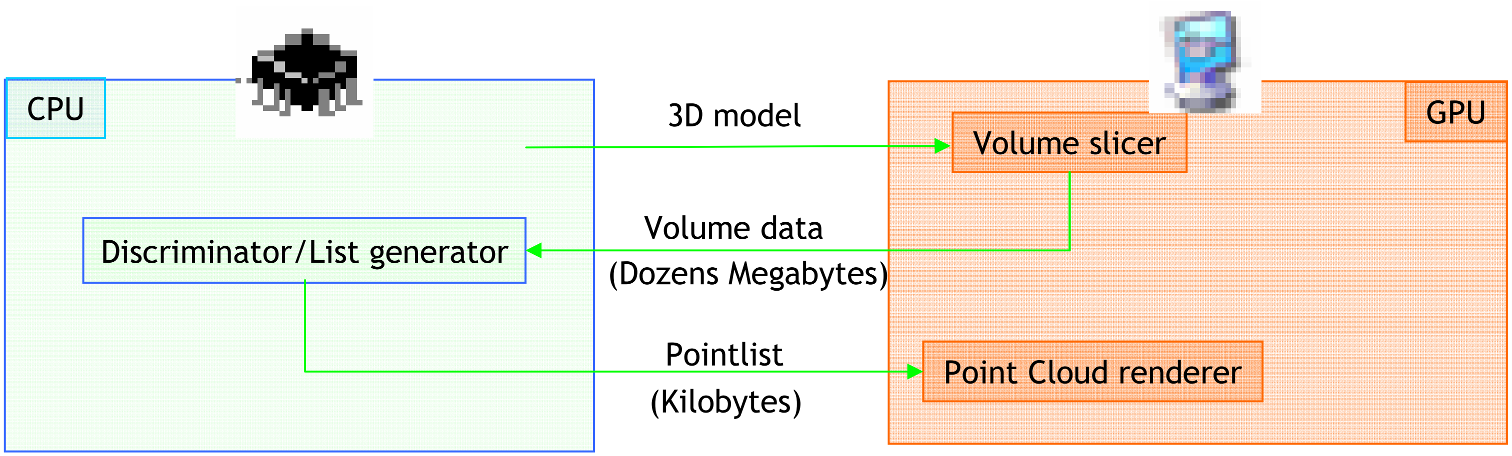


"Lattice": 2D mapping of 3D volume

- **Side effect: Following issues become a 2D problem.**

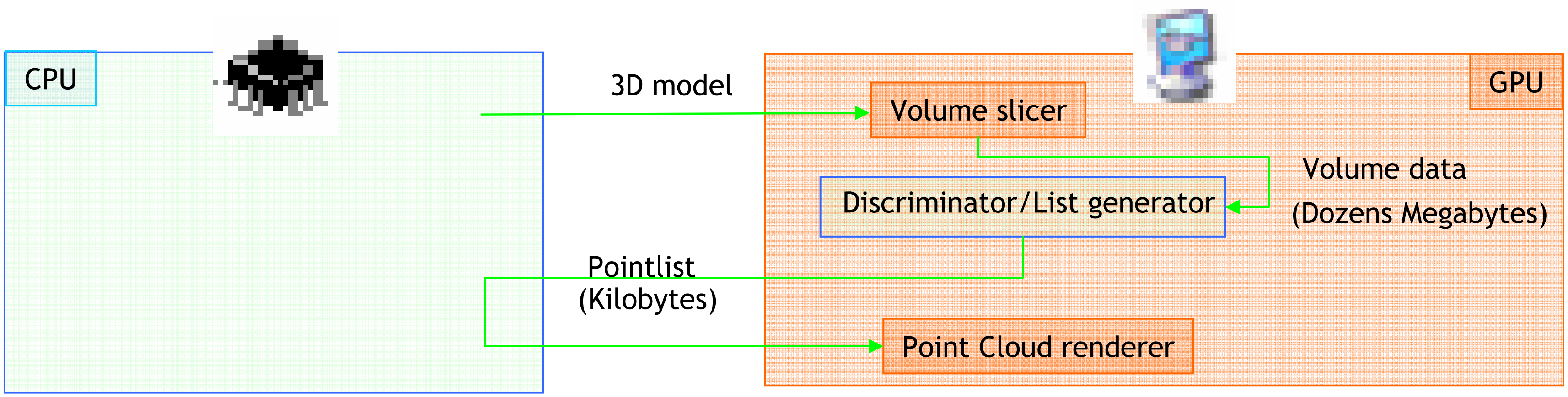
Current problem

- 3D volume is on GPU, find active voxels there
- Require dynamically growing list of point coordinates…
- **But: Bus transfers are expensive**.



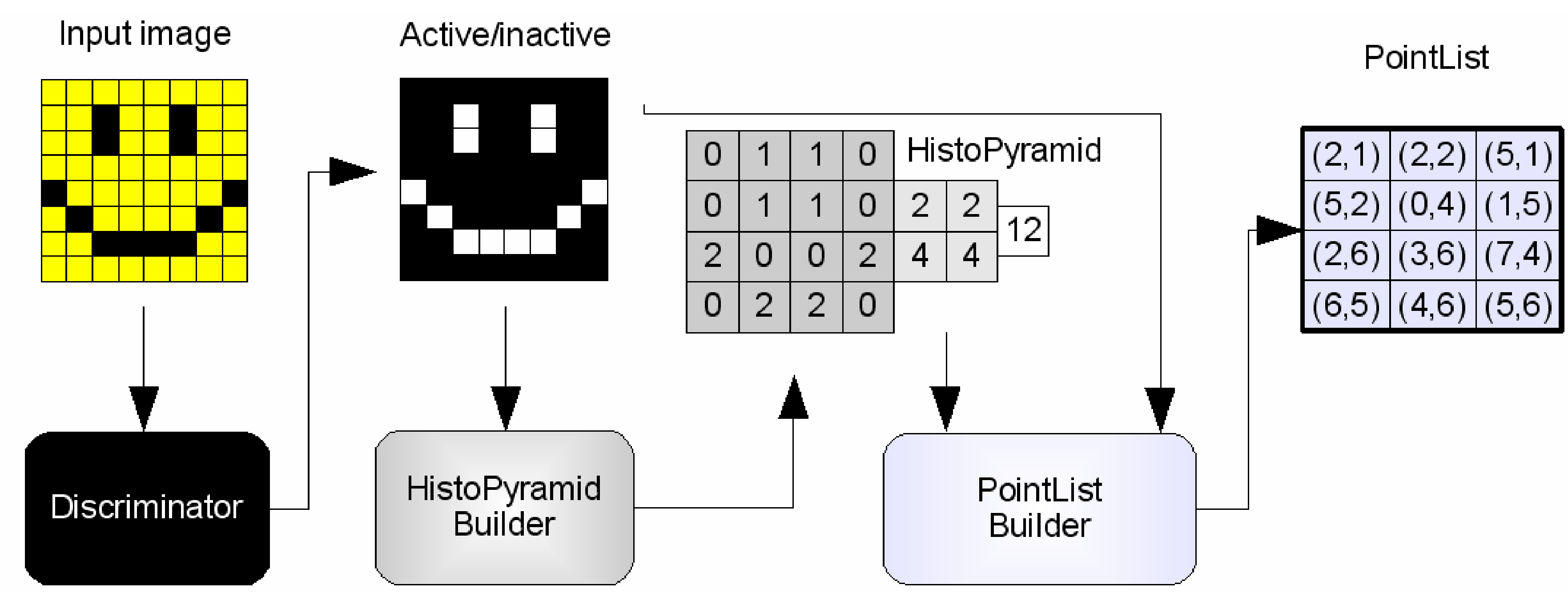
Our solution

- A 2D/3D algorithm which runs on Shader Model 3.0 *)
- See it as data compaction problem (Cell = Pixel/Voxel)
  Empty cells are "useless air", only interesting cells remain.
- Data compaction on stream processors active area of research (Horn et al, GPU Gems 2; Sengupta et al, Edge Workshop 2006)



*) SM 2.0 possible, but cumbersome

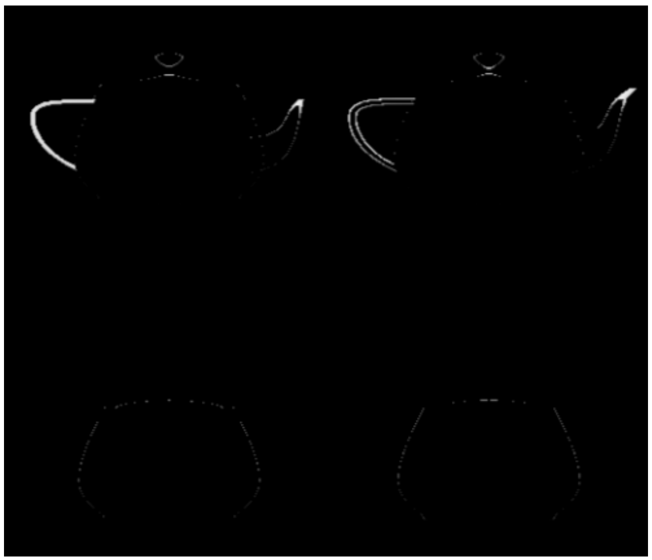
Overview, data compaction



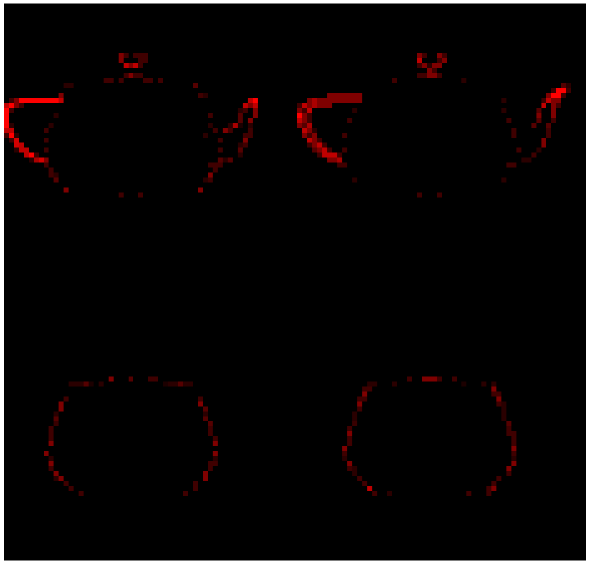
http://tinyurl.com/y5d8sh

Algorithm: Discriminator

- Tells active cells from inactive/empty ones.
- Easy criterion in our case: Alpha = 1.



Data input

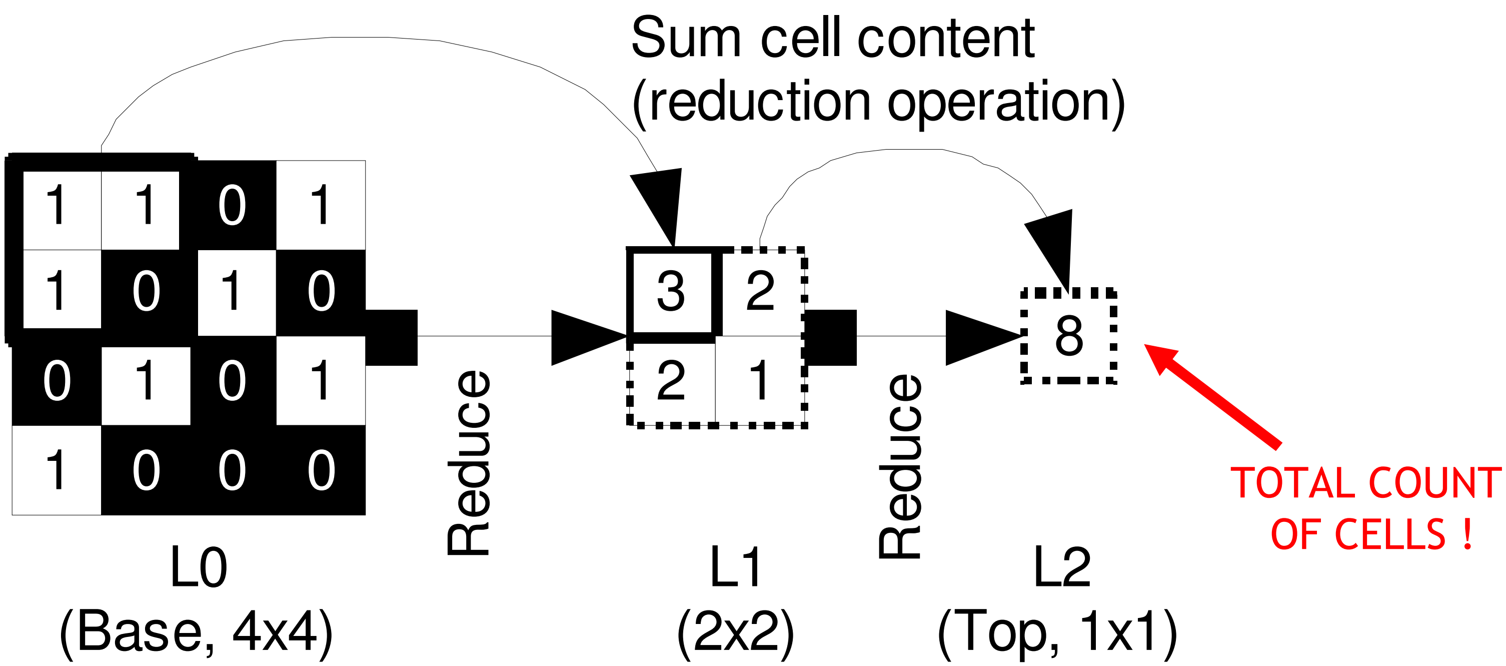


Base level of HistoPyramid

- More complicated discriminators in the paper!

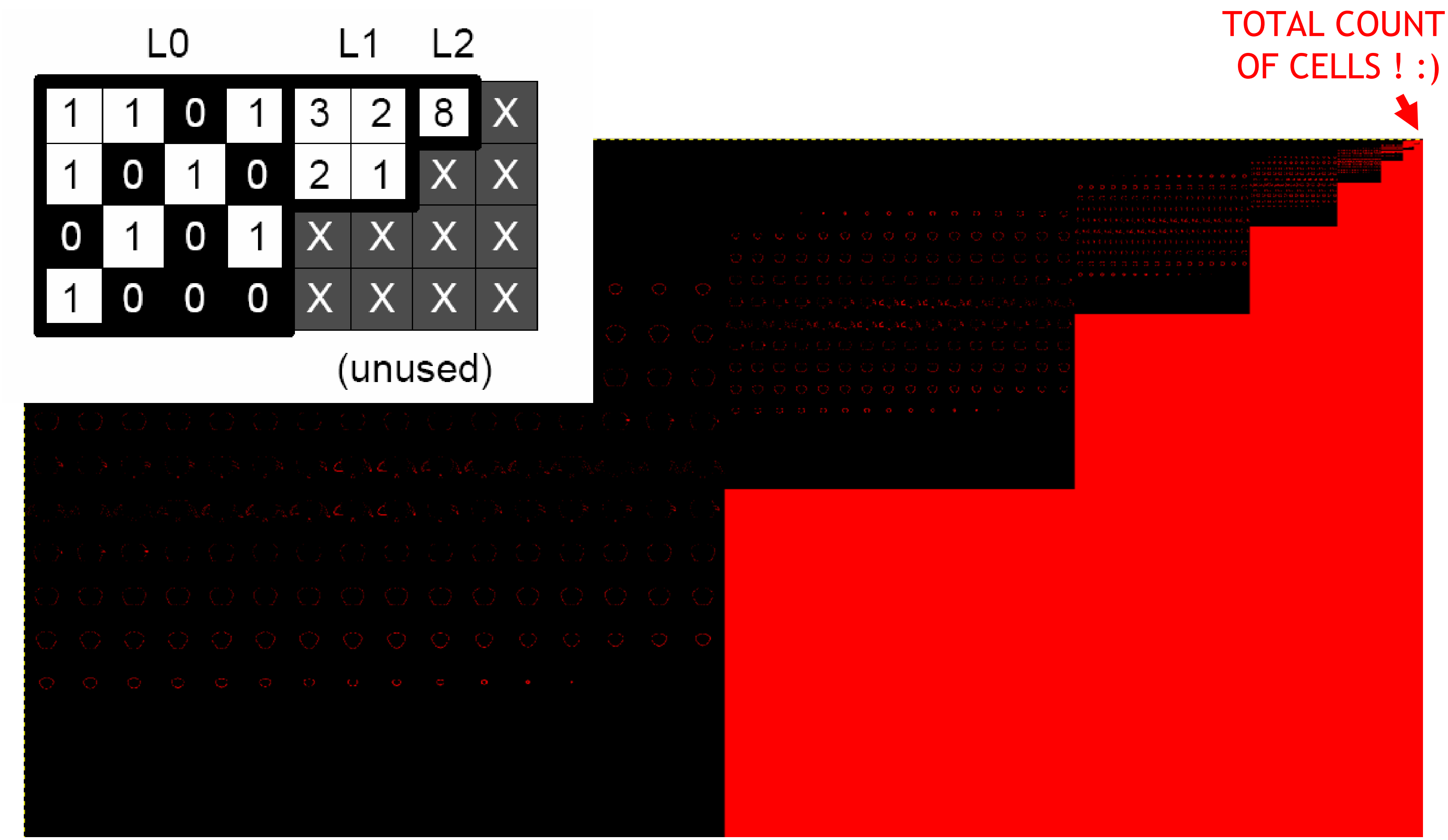
Algorithm: HistoPyramid Builder

- Hierarchically sums up active element count.
- Similar to mip-mapping (w/o averaging).



http://tinyurl.com/y5d8sh

Algorithm: HistoPyramid Builder's output

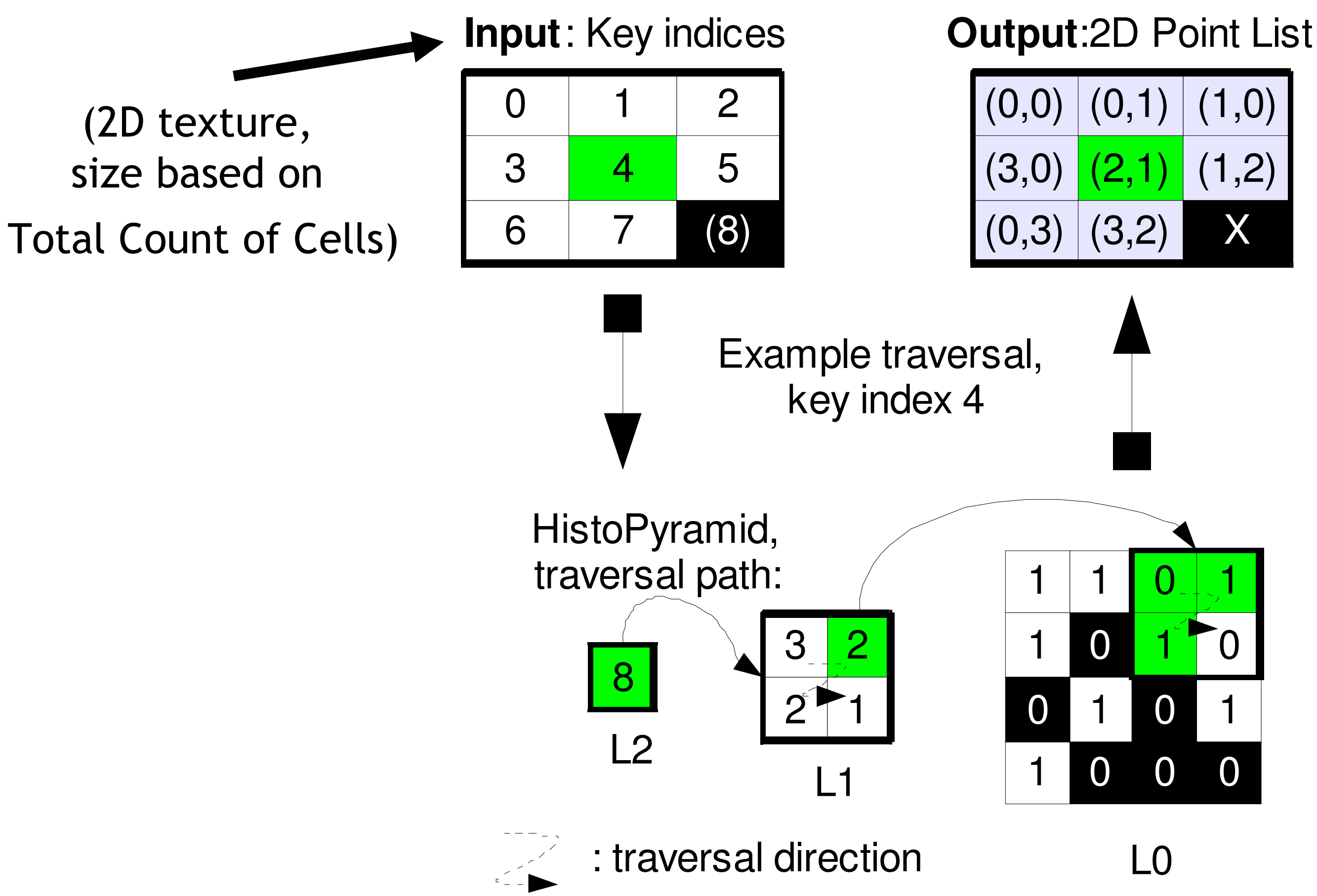


Histopyramid for Teapot

http://tinyurl.com/y5d8sh

Algorithm: PointList Builder

- Traverses HistoPyramid top-down to generate PointList.



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Algorithm: PointList Builder's output

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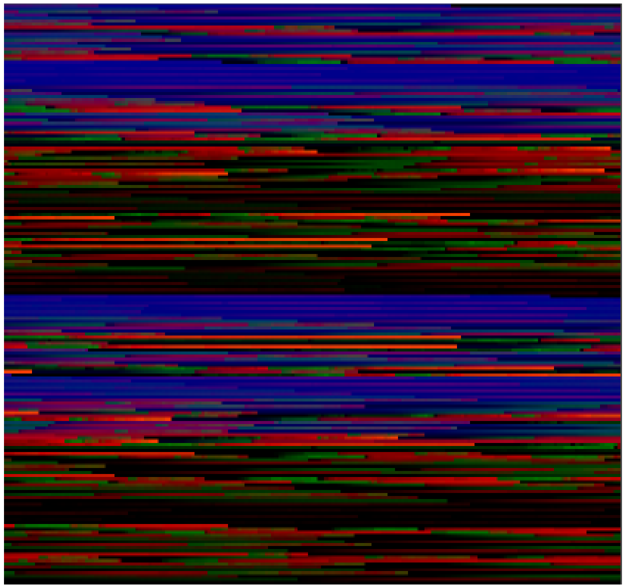
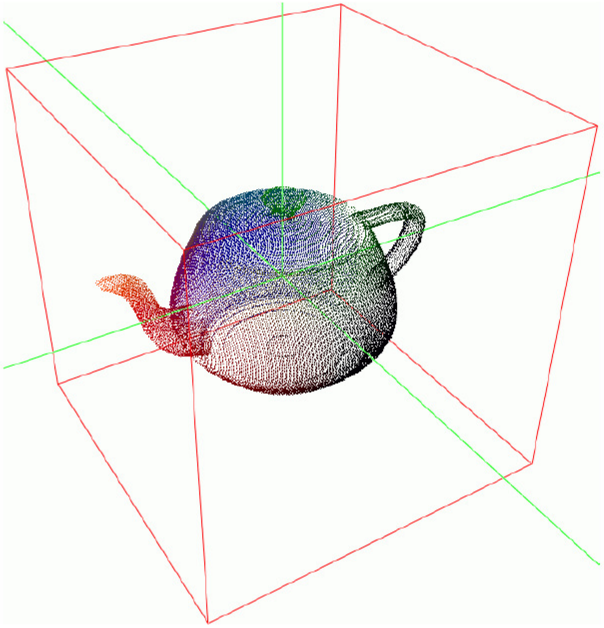
- A 2D texture listing active cells' 3D point coordinates.
- (2D to 3D mapping happens in PointList Builder)



PointList for Teapot.
false colors: 3D positions



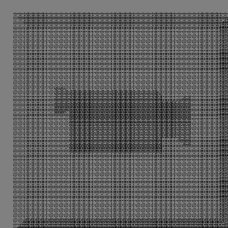
Example image,
PointCloud renderer

Done !

Results

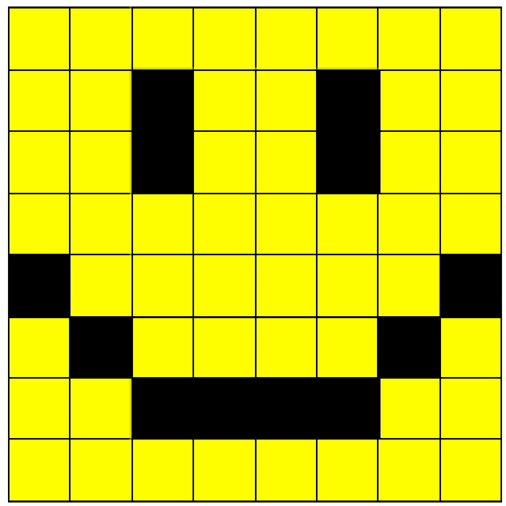
- Result: Real-time particle cloud (Art Tevs)

- Result: 3D Volume Analysis
  (Vector Field Contours, Tom Annen et al)



Future Directions

- Feature detection on GPU
- Geometry generation (SM 3.0 marching cubes)
- Real-time compression
  (with e.g. wavelet analysis)
- Conversion to SM4.0, and of course:
  "Showdown" with SM4 Geometry Shaders ;)
- Other uses for HistoPyramid
  (complete: Region Quadtrees/Octrees on GPU)
- Your ideas ? Discussions welcome !



Thank you !

http://tinyurl.com/y5d8sh

HistoPyramids vs. Geometry Shaders

- SM4.0 GPUs now have one option to create lists: Geometry Shaders.
- Used to delete and create geometry on the GPU.
- Still unclear if HistoPyramids become obsolete:
- Option 1: Route the whole data input through the geometry shader and let it “weed out” the empty cells.
  Vertex shader applied to millions of points ?
- Option 2: Let geometry shader traverse the data input, and generate geometry for all found cells.
  Can geometry shader create more than 1024 points?

Problems in GPU Feature detection

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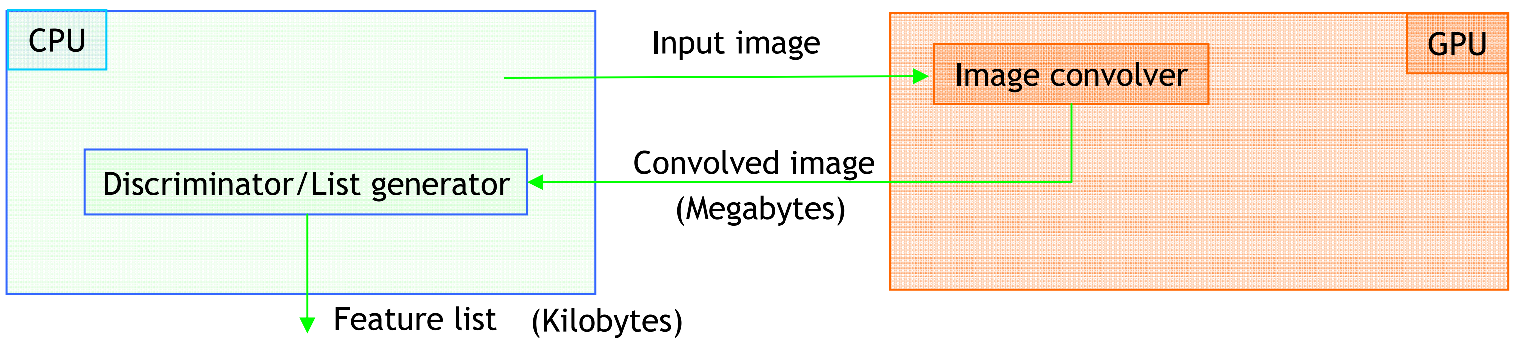
- Image analysis: GPU can convolve images.
- Feature points isolation: e.g. thresholding, requires dynamically growing list of point coordinates…
- GPU as a stream processor cannot generate this, must download to CPU.
- Bus transfers are expensive, hence:
  Speed advantage only for complex convolvements.



Speeding up GPU Feature detection

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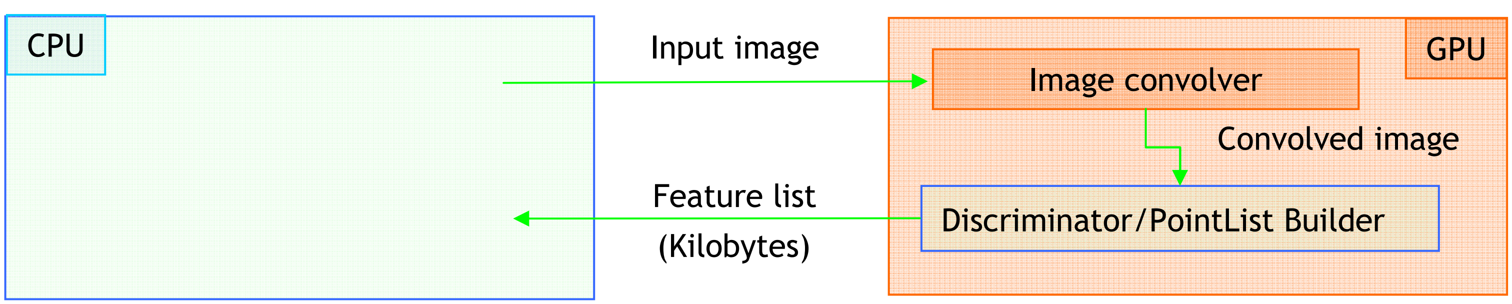
- We introduce a 2D/3D solution which runs on Shader Model 3.0.
- Make it a data compaction problem (Cell = Pixel/Voxel)
  Uninteresting cells are “useless air”,
  only interesting cells (feature points) remain
- Data compaction on stream processors
  active area of research (Horn, GPU Gems 2)
- Hence:



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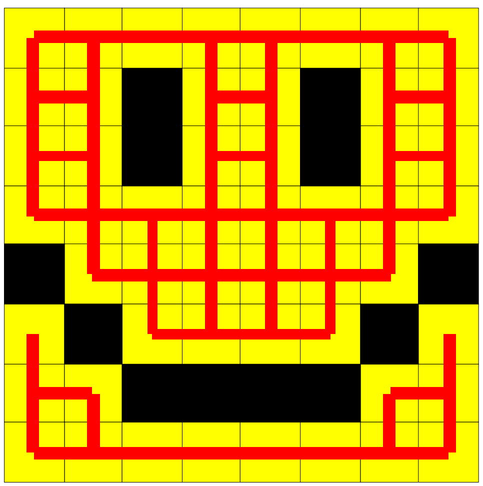
Sketch: 3D HistoPyramid

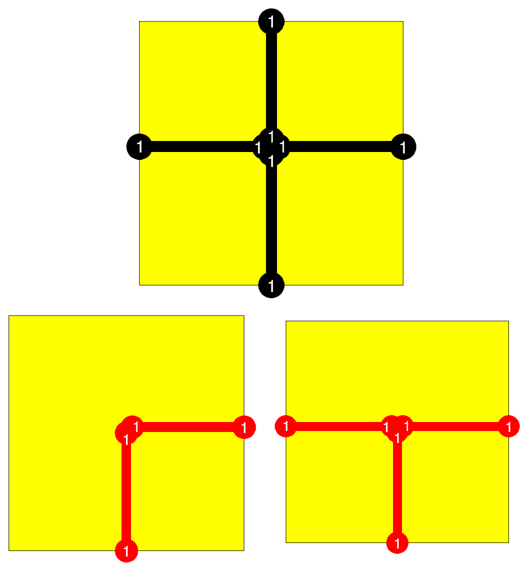
- Each pyramid level is a 3D volume.
- Like in mipmapped 3D volumes, the volumes are halved in size for every level.
- Thus, every time, 8 cells get reduced into one.
- PointList Builder accesses 3D textures one by one.
- Implementation obstacle:
  - Cannot easily generate 3D volume mipmaps on NV40 architecture without internal copying (Missing render-to-3Dtexture support).
  - The alternative, laying out several 3D volumes in one 2D texture, is very cumbersome and trashes cache behaviour.

Sketch: Geometry generation

- At base level, the discriminator calculates $n_{x,y}$, the number of intended vertices at each cell (x,y) from neighbor information (think: Marching Cubes from 3D volume).
- HistoPyramid will sum up the count of all intended vertices.



Intended line geometry



Discriminator:
Vertex creation template &
Example, $n_{x,y}$, first cells

4	6	4	4	4	4	6	4
6	6	0	6	6	0	6	6
6	6	0	6	6	0	6	6
4	8	6	8	8	6	8	4
0	4	8	8	8	8	4	0
2	0	4	6	6	4	0	2
6	4	0	0	0	0	4	6
4	6	4	4	4	4	6	4

HistoPyramid base level

http://tinyurl.com/y5d8sh

Sketch: Geometry generation

- GeometryBuilder, derived from PointList Builder, will end up parallelly ($n_{x,y}$ times) at cell (x,y) during top-down traversal.
  But it will know this (as it knows the initial index for cell (x,y)), and thus create the intended *[1.. $n_{x,y}$]*-th vertex from a lookup table.

4	6	4	4	4	4	6	4
6	6	0	6	6	0	6	6
6	6	0	6	6	0	6	6
4	8	6	8	8	6	8	4
0	4	8	8	8	8	4	0
2	0	4	6	6	4	0	2
6	4	0	0	0	0	4	6
4	6	4	4	4	4	6	4

22	14	14	22
24	20	20	24
6	26	26	6
20	8	8	20

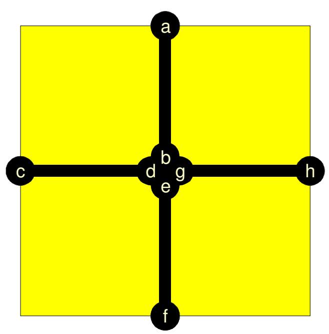
80	80
60	60

280

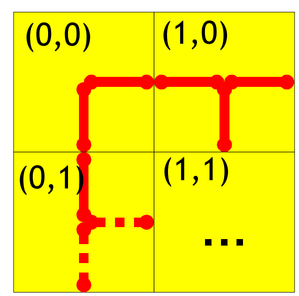
Created HistoPyramid

(0,0,e)	(0,0,f)	(0,0,g)	(0,0,h)
(1,0,c)	(1,0,d)	(1,0,e)	(1,0,f)
(1,0,g)	(1,0,h)	(1,1,a)	(1,1,b)
(1,1,..)	...		

GeometryBuilder's vertex output list



GeometryBuilder's vertex creation order



Above list as geometry

Real-time QuadTree analysis

- Vision task: Detect regions with common features
- "Common feature": Low variance around average color
- Usually very time-consuming, by far not real-time
- Our Answer:
  - Extension of GPU point list algorithm
  - Only create simple region geometry, region quadtrees
  - Typical analysis time: 640x480 in 15 ms
- Useful for:
  - Color grouping
  - Motion vector clustering
  - Acceleration of grid calculations

Results

ffkvadrat: Real-time quadtree analysis

Video frame, Edge analysis, several results

(Footage by GusGus, *Call of The Wild*)