Extraction of tiled top-down irregular pyramids from large images

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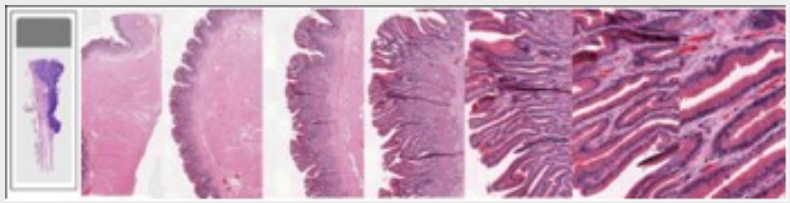
Context

Application

- ANR Project FoGrImMi: Search Through Large Microscopic Images
- Medical imaging (histology, cytology)
- Whole Slide Imaging for microscopical images
- Large multi-resolution images (30GB)



Requirements: efficient tools for automatic analysis and processing of very large images.

Objectives

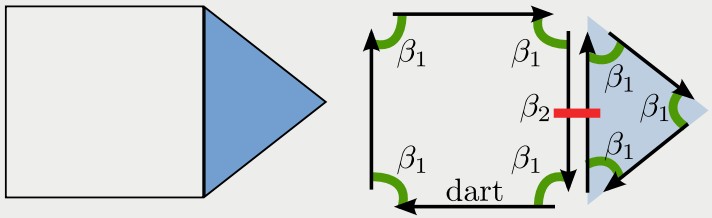
- Define a top-down topological model
- Efficient update after splitting operations
- Hierarchical structure complying with causality principle
- Memory usage

Constraints and proposed solutions

- Topological properties
  $\Rightarrow$ combinatorial maps
- Multi-resolution images
  $\Rightarrow$ hierarchical model
- Very large images
  $\Rightarrow$ top-down construction

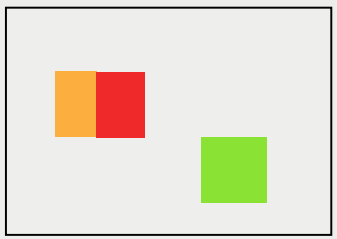
Combinatorial and Topological Maps

Combinatorial maps

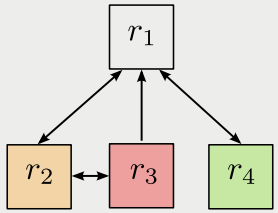


- Dart: $\sim$ half-edge
- β_1 permutation: turns around a face
- β_2 involution: opposite face

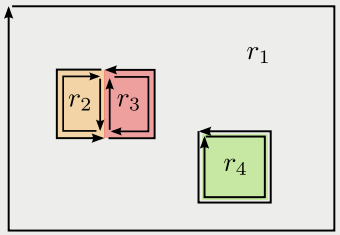
Topological maps



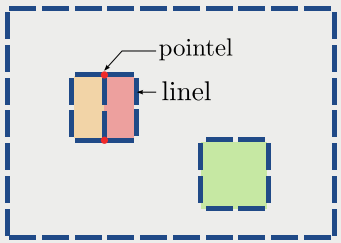
Original image



Tree of regions



Topology



Geometry

- Represent any partition
- Describe adjacency and inclusion relationships
- Efficient processing algorithms

Framework for Irregular Combinatorial Pyramids

Definition

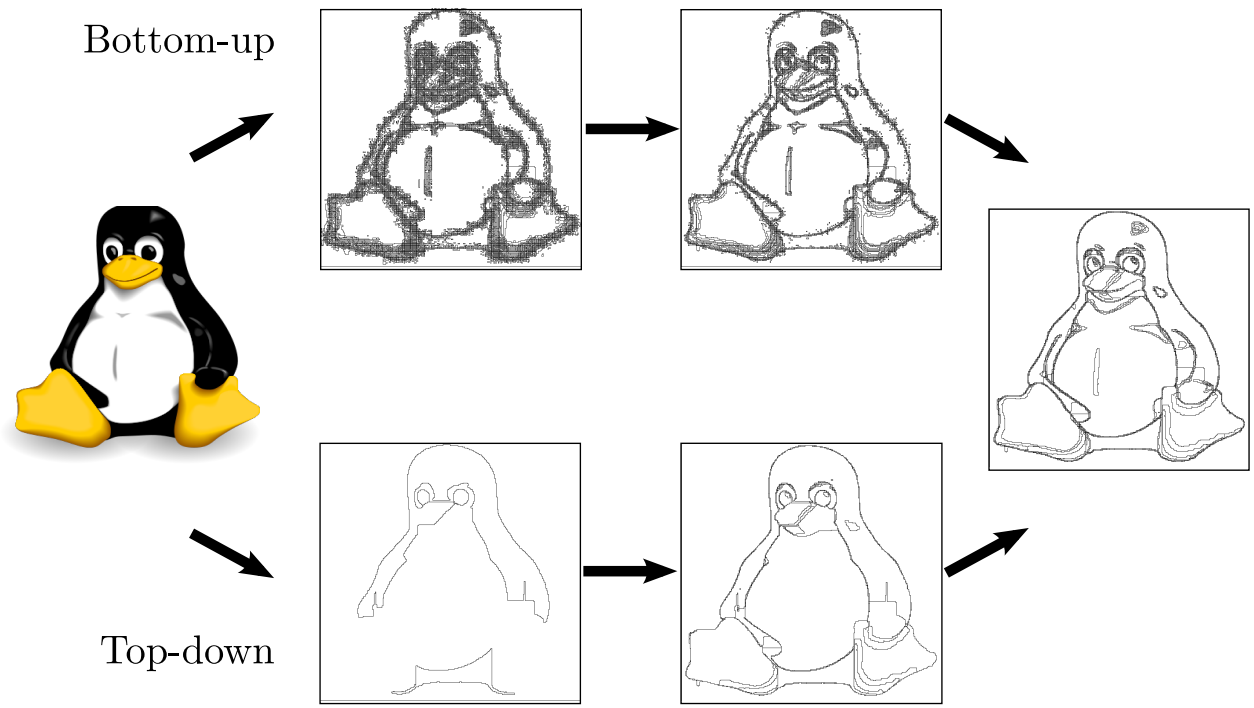
Stack of combinatorial maps successively transformed.

Bottom-up pyramids

- Main operation: merge
- Drawbacks:
  - encode the whole initial partition $\Rightarrow$ high memory requirements

Top-down pyramids

- Main operation: split
- Advantages:
  - encode upper levels until given segmentation
  - focus of attention



Top-down Pyramidal Model

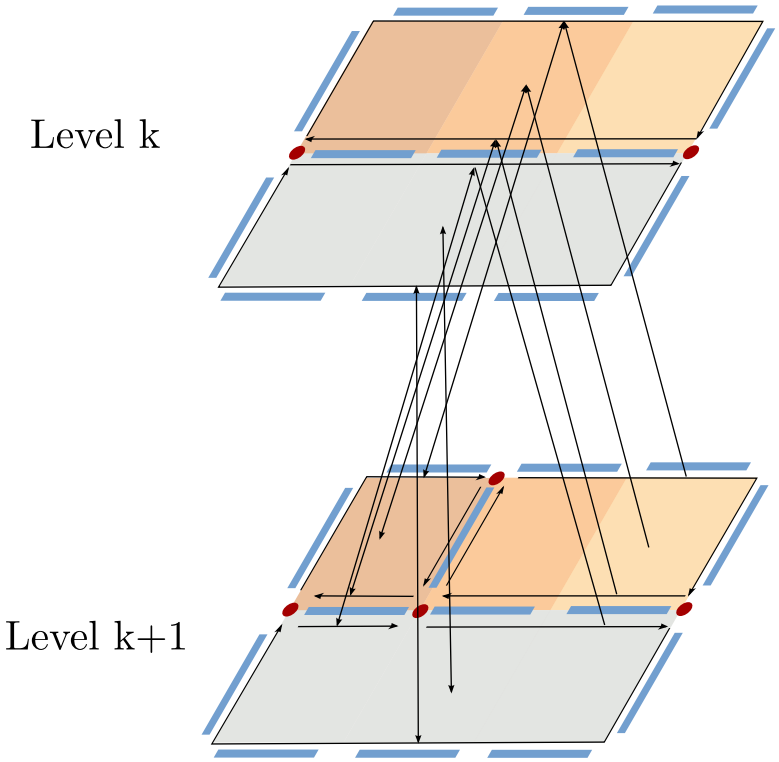
Definition

- Stack of topological maps
- Splitting operations from one level to another
- Up/down relations between darts and regions
- Causal structure

Construction

- Copy: level duplication
- Link: hierarchical relations
- Refine: splitting operation
  - use of segmentation criteria
  - splitting: creates one region/pixel
  - merging

Original image



Top-down pyramid

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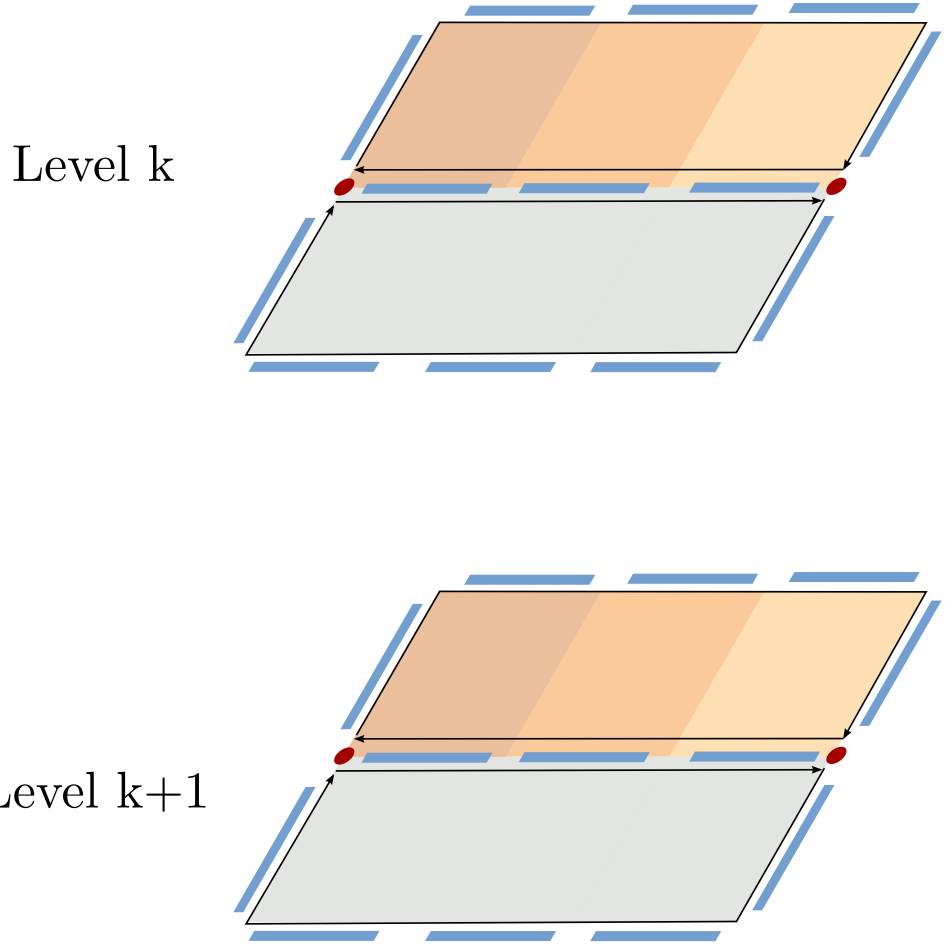

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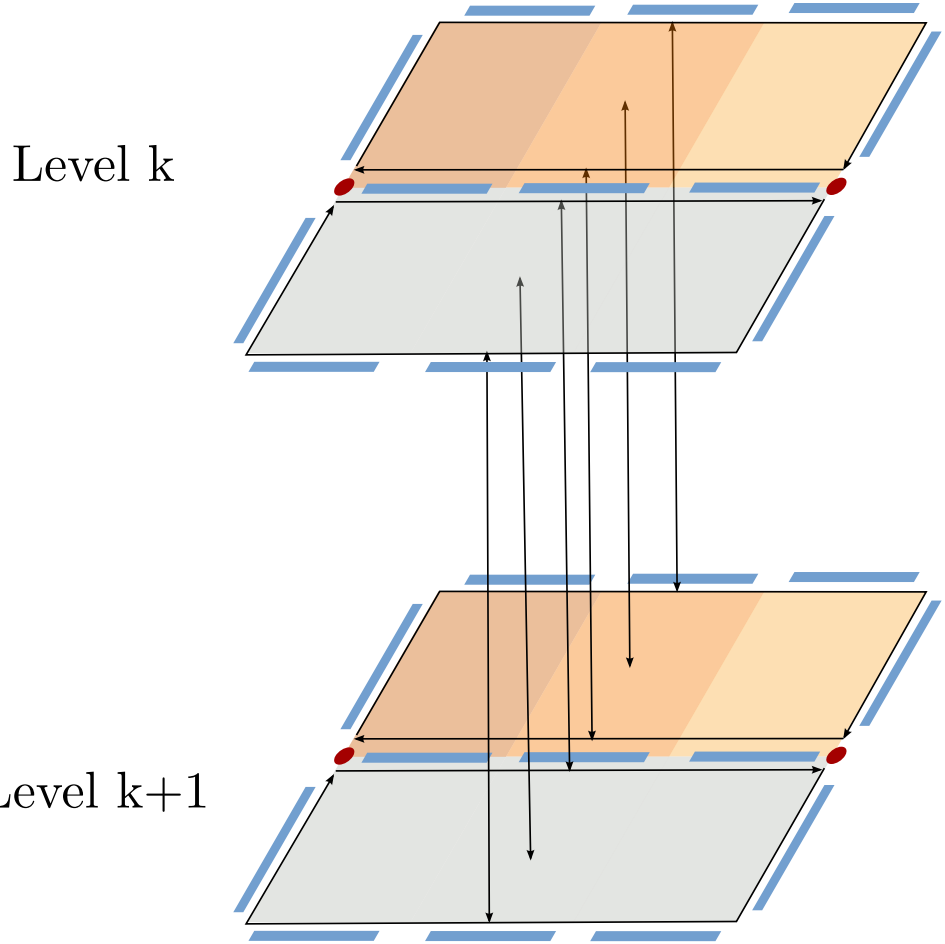

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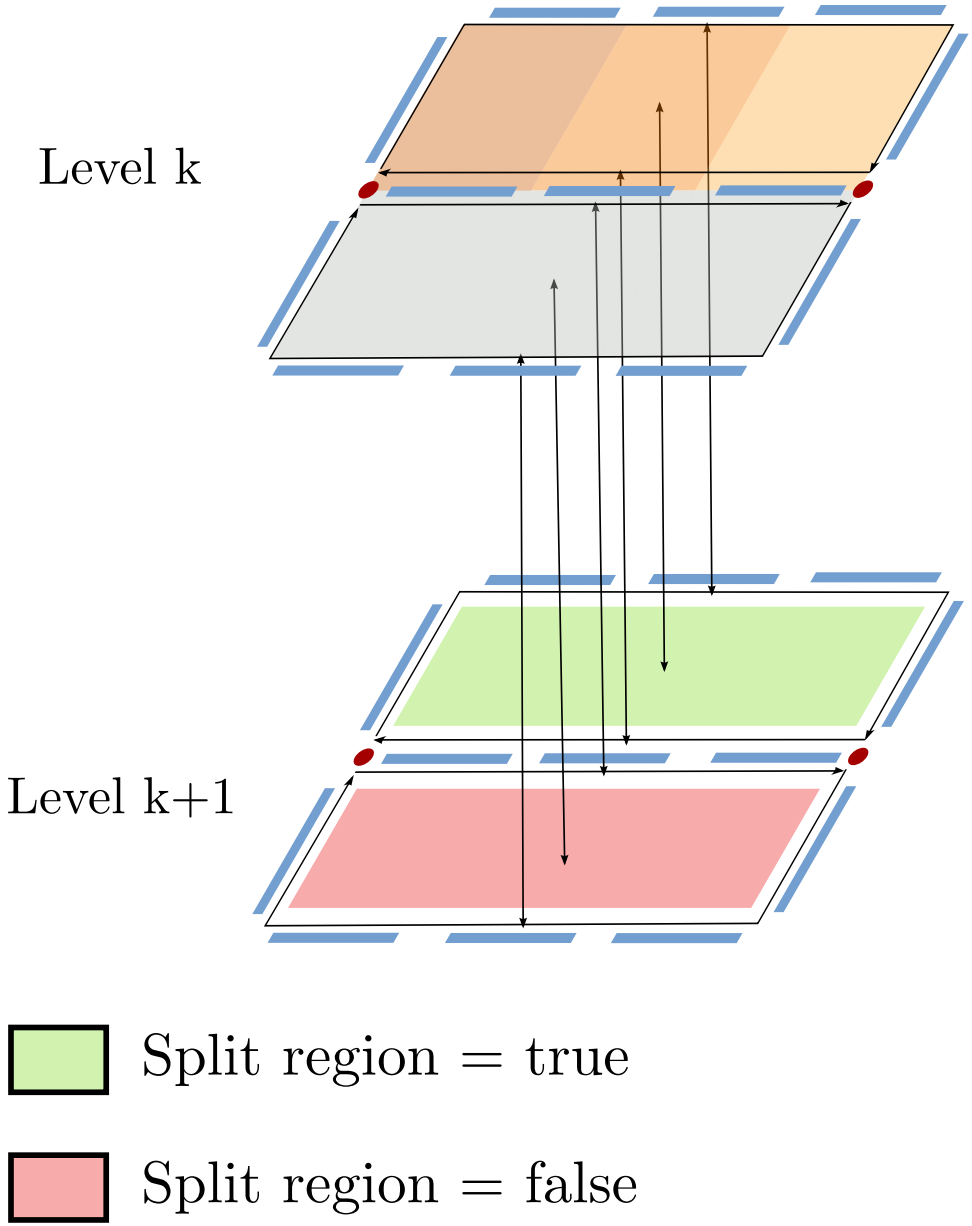

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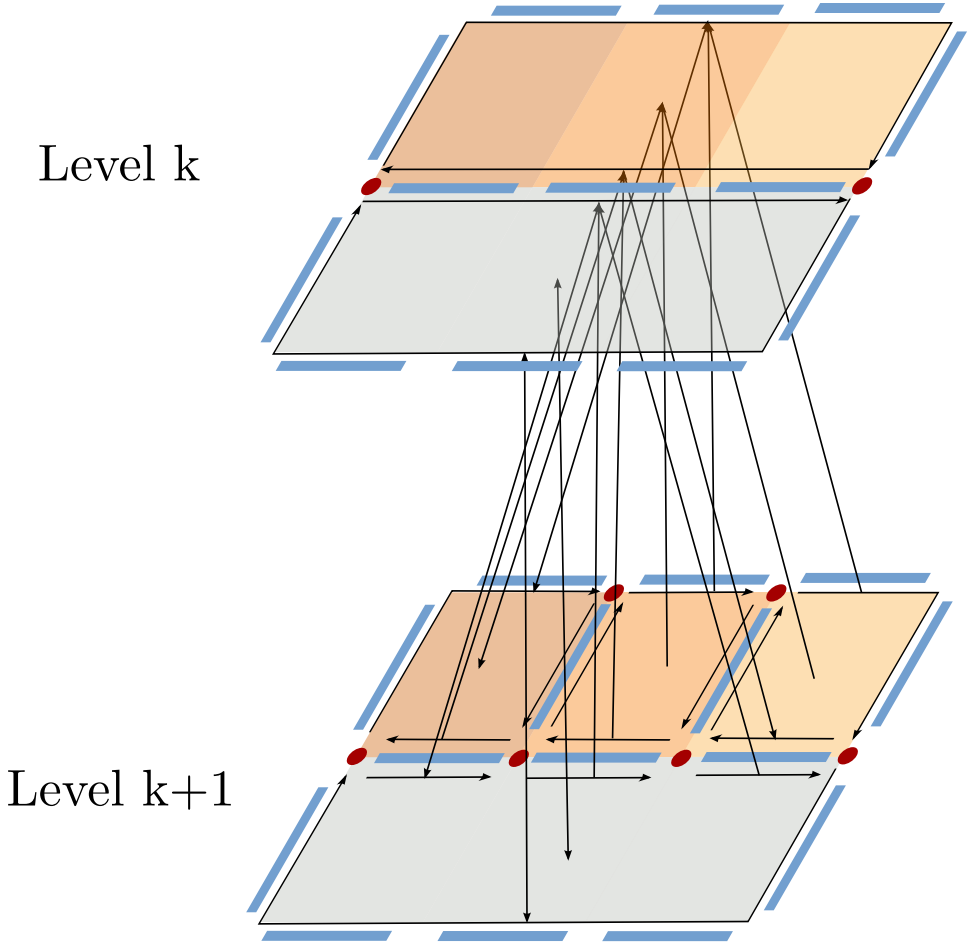

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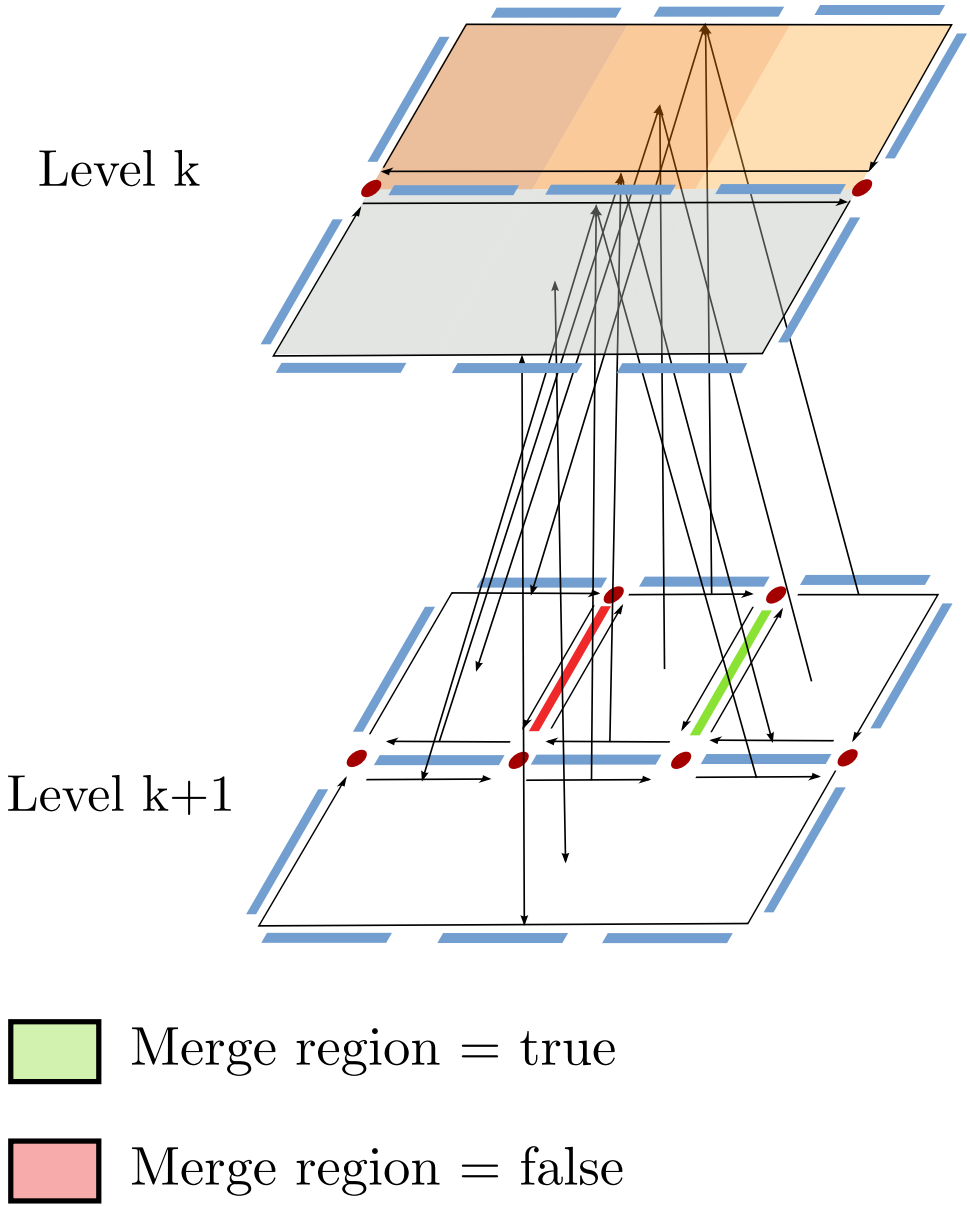

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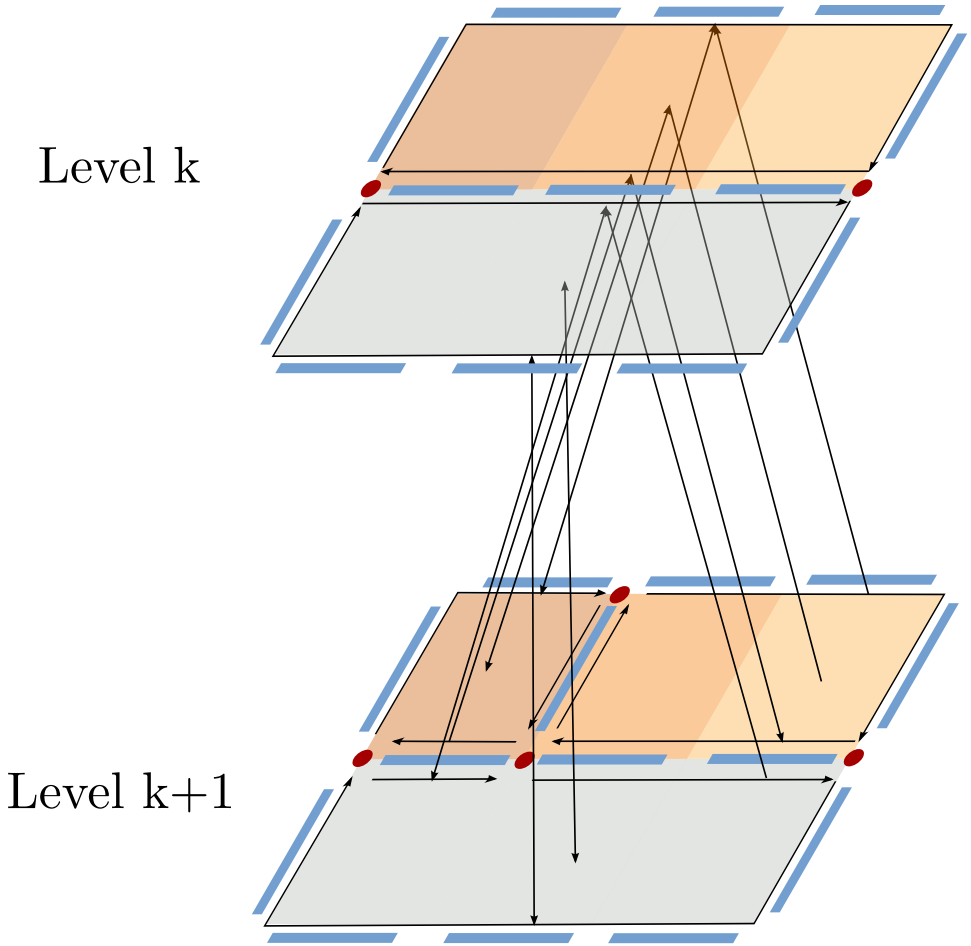


Presentation

Constraint

- Top-down construction *only minimizes* memory
- Application requires a *bound* memory usage

Proposed solution

- Geometrical division of a map in topological tiles
- Insertions of fictive darts on the borders

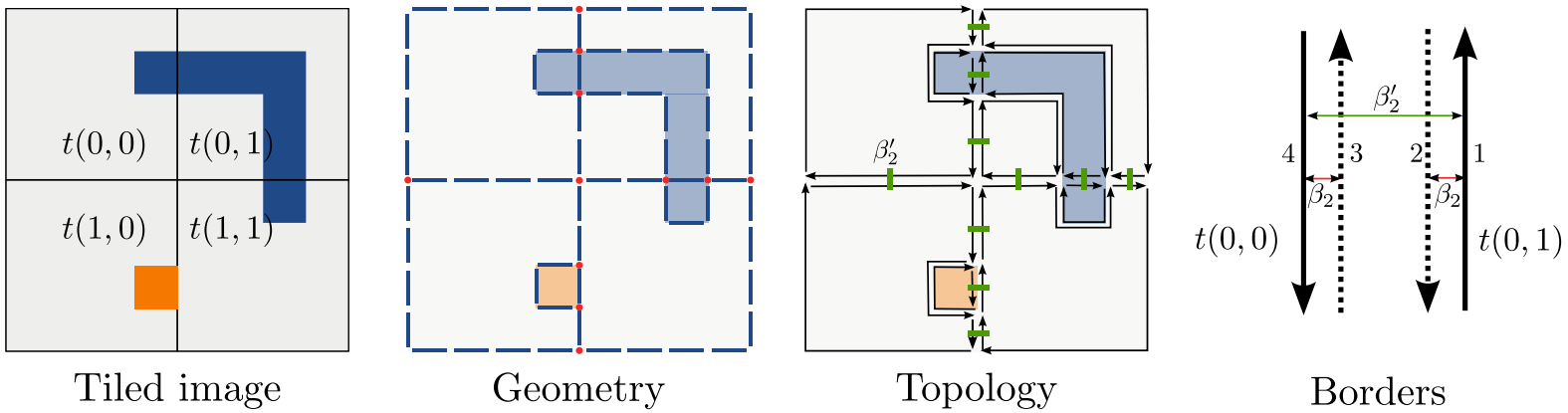
Integration in the pyramidal model

- New operator on darts for adjacent tiles connection
- Swap/load operations
- Incremental construction

Definitions

Topological tile

- Topological tile t(i,j,k): partition of a geometrical subdivision (i,j) at level k
- t(i,j,k+1) deduced from t(i,j,k) by splitting operation

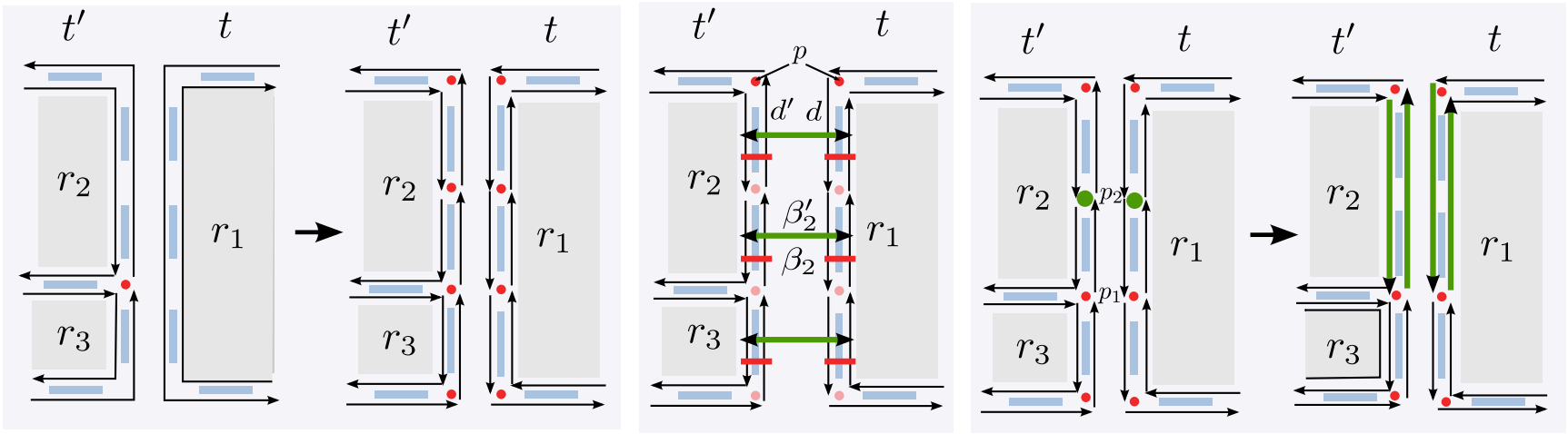


Tiled image | Geometry | Topology | Borders

Tiled top-down pyramid

- Tiled top-down pyramid: set of topological tiles
- Local pyramid: set of tiles loaded in memory

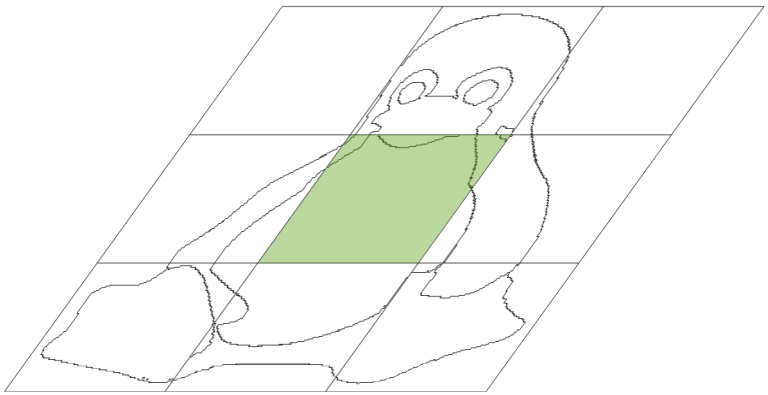
Connection of Adjacent Tiles

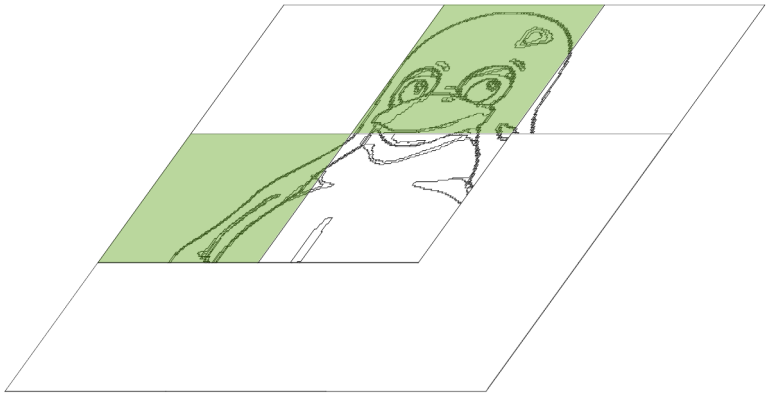


Main steps

- Splitting borders
  $\Rightarrow$ ensures two adjacent tiles share the same number of darts on their borders
- Connection of the darts on shared border
  $\Rightarrow$ set β'_2 relations
- Simplification step for minimality
  $\Rightarrow$ if the degree of a vertex equals 2 in both tiles

Extraction of a Tiled Pyramid





Algorithm

For each tile $t(i, j, k)$ in level k:

- Load $t(i-1, j, k+1)$ and $t(i, j-1, k+1)$
- Create $t(i, j, k+1)$ from $t(i, j, k)$
- Connect the neighbors of $t(i, j, k+1)$
- Save $t(i, j, k+1)$, $t(i-1, j, k+1)$, $t(i, j-1, k+1)$ and $t(i, j, k)$
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- Scanline extraction
- **4 tiles at most** in memory

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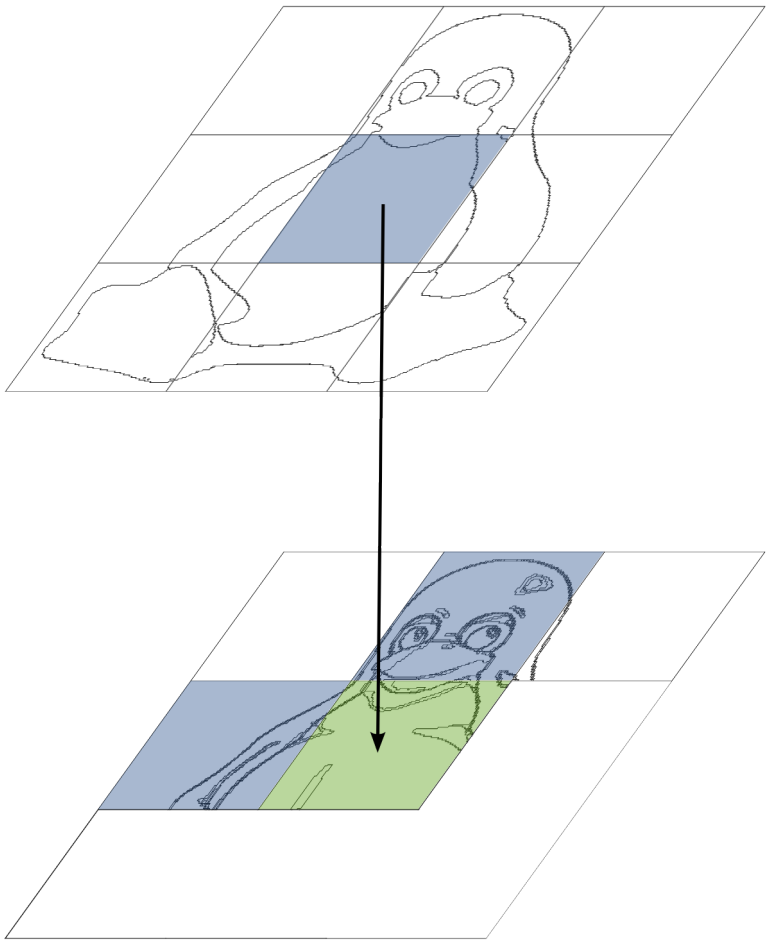

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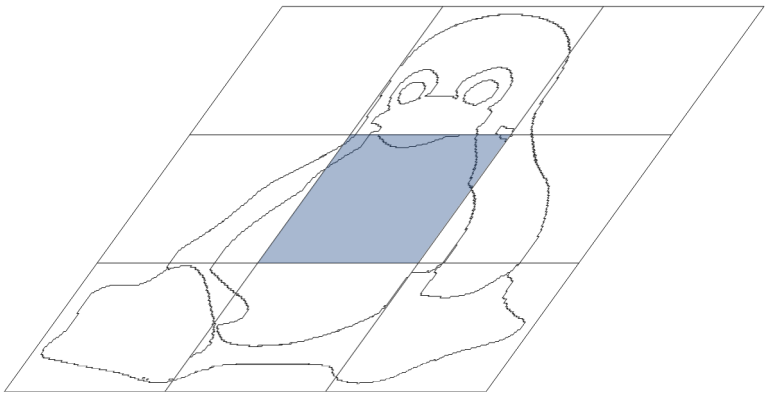

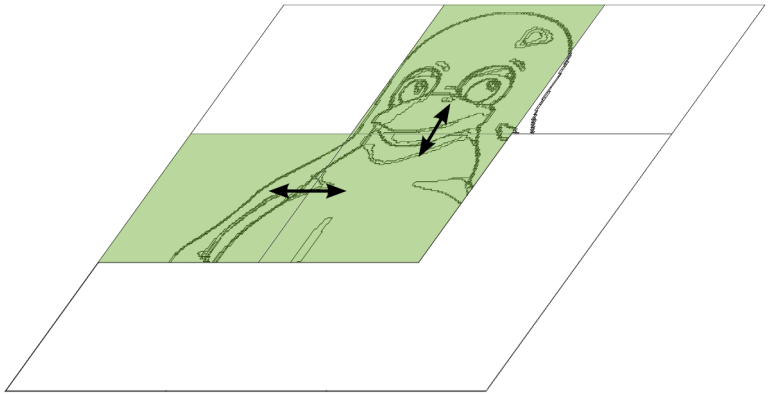

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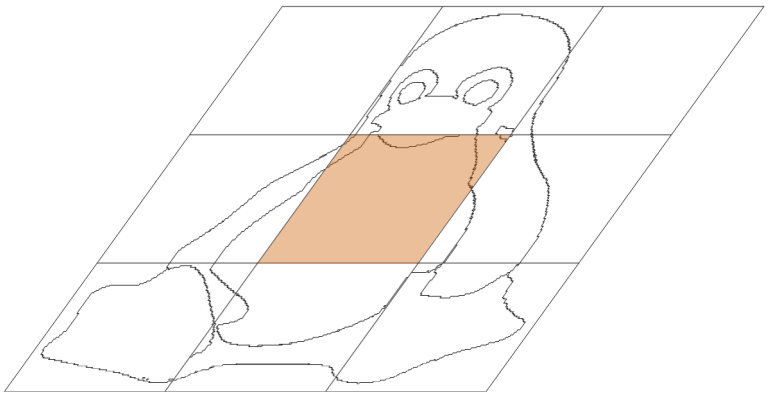

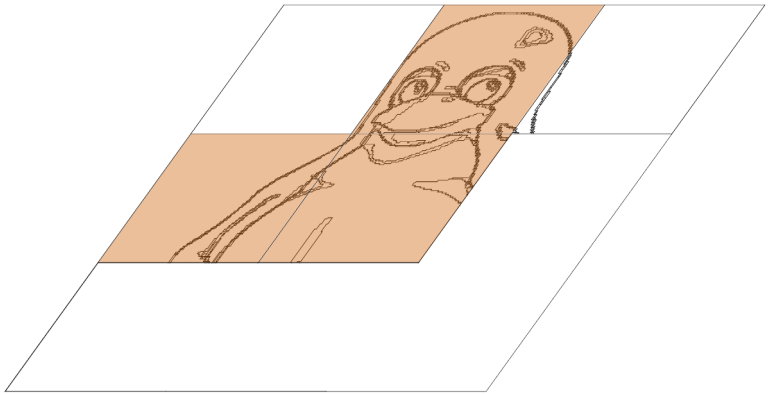

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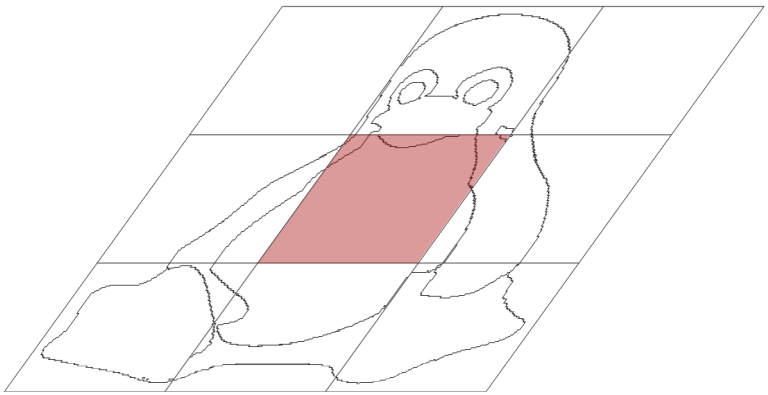

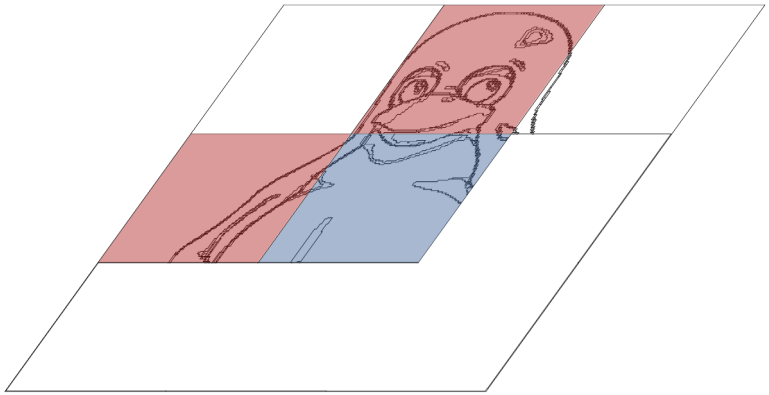

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Criteria

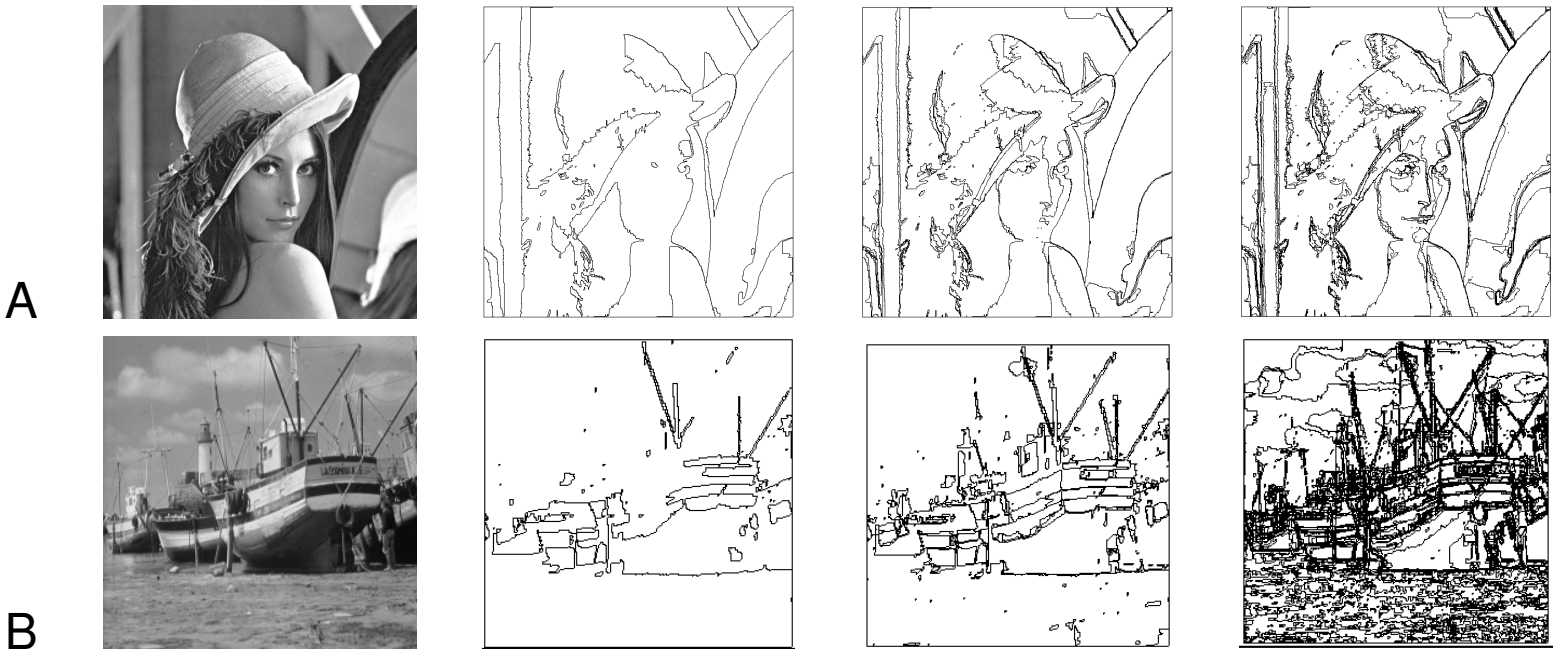

Figure: Basic segmentations for 4 levels pyramids. (A) Hierarchical criterion: standard deviation of up regions; (B) Colorimetric criterion: average gray levels comparison.

Criteria can take into account:

- colorimetric features of regions
- topological features of a level
- hierarchical features of the pyramid

Construction from a Multi-resolution Image

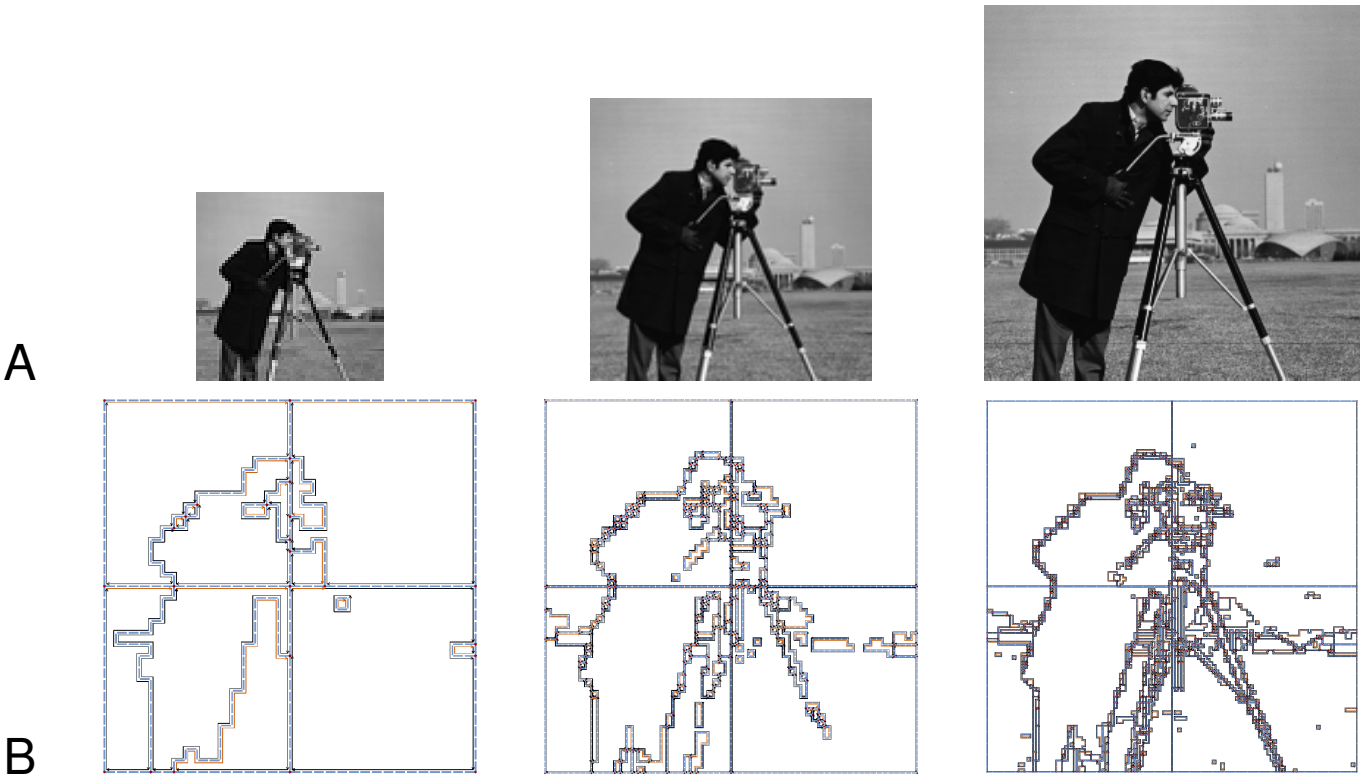

Figure: (A) Image resolutions; (B) Pyramid levels.

- Tiled structure $\Rightarrow$ fictive borders are displayed
- Multi-resolution images
  $\Rightarrow$ pyramid levels and image resolutions are independent notions
- Irregular pyramid $\Rightarrow$ irregular model within the tiles

Results

Table: Memory usage: extraction for different scalings of image *Lena*.

image side (px)	tiles per level	memory (MB)	disc (MB)
512	1	92	7
2 048	16	95	20
8 192	256	95	272
32 768	4 096	111	4 315

- Extreme configuration: 4 levels 32K*32K
- Natural segmentation: lots of darts and regions
- Controlled memory usage

Conclusion

- Definition of a data structure
  - topological representation
  - hierarchical causal structure
  - top-down construction

- Implementation
  - based on topological maps
  - tiled subdivision
  - colorimetric, topological and hierarchical segmentation criteria
  - integrated with multi-resolution images

Perspectives

- Segmentation aspect
  - integration of clustering and quantization methods
  - specific application to medical images

- Model improvements
  - compare different strategies for the subdivision in tiles
  - faster processing for very large images
  - different splitting techniques
  - multi-threading support