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Introduction

The Problem

- Large images do not fit in RAM
- Algorithms have to use multi-core CPUs
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ChunkedArray

- Holds images divided into smaller blocks
- Only loads blocks currently required, caches them
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ChunkedArray

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Needs adjusted algorithms to be efficient
Definition

Let \( X \subseteq \mathbb{Z}^n \), \( I \) an image on \( X \).
Let \( P(I(x), I(y)) \) be a symmetric predicate defined for each adjacent pair of coordinates \((x, y)\) in \( X \).
Define an undirected graph \( G = (X, E) \) by setting

\[
(x, y) \in E \iff x \text{ is adjacent to } y \land P(I(x), I(y)).
\]

A labeling of \( I \) according to \( P \) is an image \( J \) on \( X \) such that

\[
\forall x, y \in X : J(x) = J(y) \iff x \sim y \text{ in } G.
\]
Connected Components Labeling

MapReduce

MapReduce

1. Divide problem into smaller subproblems
2. Map a function on subproblems (possibly in parallel)
3. Reduce results to a global result
Connected Components Labeling

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MapReduce on ChunkedArrays

1. Image is already stored in separate chunks
2. Map algorithm for MultiArrays on every chunk
3. Reduce subresults to global result
Connected Components Labeling
Implementation - Map Stage

Apply map function

► Iterate over chunks with ChunkIterator
► Use labelMultiArray to create a local labeling for each chunk
► Save number of local labels assigned for each chunk
Connected Components Labeling
Implementation - Reduce Stage

Goal:
Merge local labels to global labels
Connected Components Labeling
Implementation - Reduce Stage

Goal:
Merge local labels to global labels

Unique global ids for local labels

- Calculate an id_offset for each chunk such that id_offset + local_label_id yields globally unique label ids
Connected Components Labeling
Implementation - Reduce Stage

Goal:
Merge local labels to global labels

Unique global ids for local labels
▶ Calculate an id_offset for each chunk such that id_offset + local_label_id yields globally unique label ids

Merge labels
▶ Union-find data structure for global label ids
▶ Iterate over all adjacent chunks with GridGraph
▶ Iterate over adjacent pixels in different chunks with visitBorder
▶ Merge two pixels’ global labels if they satisfy the predicate
▶ Replace local labels by global labels (optional)
# Blockwise Labeling

## Usage

```cpp
#include <vigra/blockwise_labeling.hxx>
using namespace vigra;

int main() {
  ChunkedArray<4, int>& data = ...  
  ChunkedArray<4, int>& labels = ... 
  LabelOptions options;
  options.neighborhood(IndirectNeighborhood)
                   .background(3);
  labelMultiArrayBlockwise(data, labels, options);
  ...
}
```
Watershed Transform

Definitions

Definition
Let $I$ be a grayscale image on $X \subseteq \mathbb{Z}^n$. $I$ can be regarded as a topographic relief by identifying darkness with height for every pixel.

A drop of water put on a pixel will flow down the steepest slope until it stops in a minimum. A watershed labeling according to the drop of water principle is an image $J$ on $X$ such that

$$\forall x, y \in X : J(x) = J(y) \iff \text{drops of water put on } I \text{ at positions } x \text{ and } y \text{ come to a halt in the same minimum}$$
Watershed Transform

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Problem: non-lower-complete images
A watershed labeling can be reduced to a connected components labeling problem with the predicate

\[ P(x, y) \iff x \text{ is the lowest neighbor of } y \lor y \text{ is the lowest neighbor of } x \lor \text{ neither } x \text{ nor } y \text{ has a strictly lower neighbor} \]
A watershed labeling can be reduced to a connected components labeling problem with the predicate

\[ P(x, y) \iff x \text{ is the lowest neighbor of } y \lor \]
\[ y \text{ is the lowest neighbor of } x \lor \]
\[ \text{neither } x \text{ nor } y \text{ has a strictly lower neighbor} \]

To decide \( P(x, y) \), all neighbors of \( x \) and \( y \) have to be considered – bad for a blockwise algorithm (pixels on chunk borders)
Solution:

- Checkout blocks slightly larger than chunks that overlap adjacent chunks by one pixel
- Save relative coordinate of lowest neighbor for each pixel in a temporary array
- Use only temporary array to decide predicate and label according to it
- Write operations only within the actual chunk size ⇒ parallelizable
Blockwise Watershed Transform

Usage

```
#include <vigra/blockwise_watershed.hxx>
using namespace vigra;

int main() {
    ChunkedArray<4, int>& data = ...
    ChunkedArray<4, int>& labels = ...
    unionFindWatershedsBlockwise(data, labels, IndirectNeighborhood);
    ...
}
```
Thank you!