Lecture 3:
Region Based Vision

Spring 2021

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Handouts & Lecture Notes

- Report in Scientific American (June 2014):

  "In each study, however, those who wrote out their notes by hand had a stronger conceptual understanding and were more successful in applying and integrating the material than those who used [sic] took notes with their laptops."

  The Pen Is Mightier Than the Keyboard

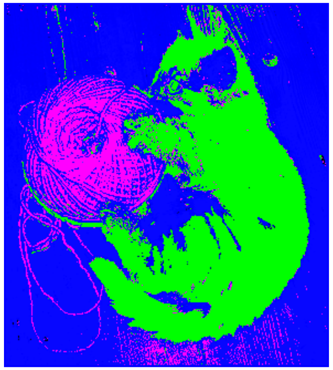
  P. A. Mueller, D. M. Oppenheimer, *Psychological Science,* Vol 25,Issue 6, pp. 1159 – 1168, April-23-2014.

- Handouts are to aid note taking, not a total replacement for note taking
- Podcasts, slides, pdfs etc on BlackBoard

Segmenting an Image

Assigning labels to pixels (cat, ball, floor)

- **Point processing:**
  - colour or grayscale values, thresholding
- **Neighbourhood Processing:**
  - Regions of similar colours or textures
- **Edge information (next lecture)**
- **Prior information: (model-based vision)**
  - I know what I *expect* a cat to look like

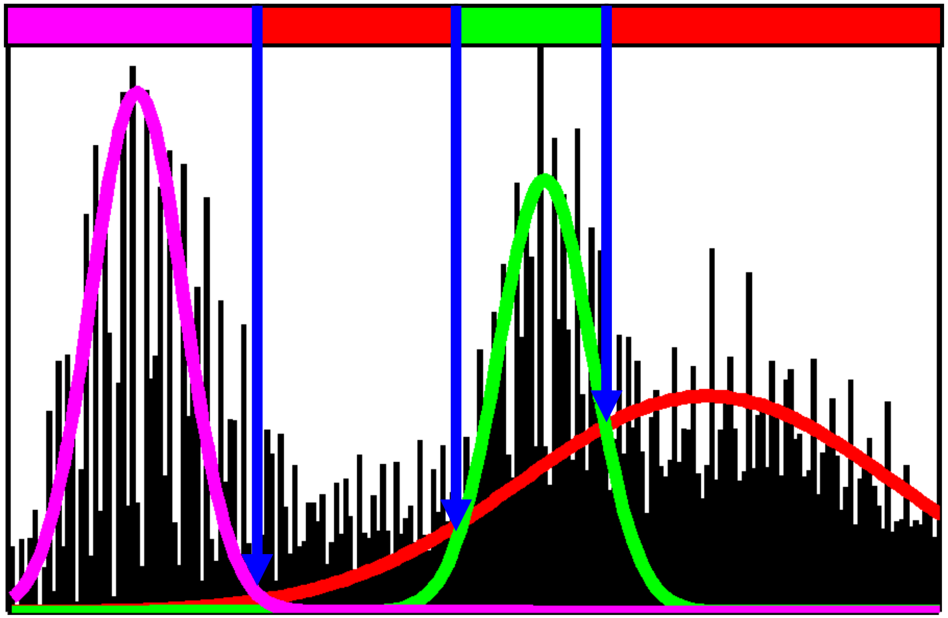


Overview

- **Automatic threshold detection**
  - **Earlier, we did this by inspection/guessing**
- **Multi-Spectral segmentation**
  - **Satellite & medical image data**
- **Split and Merge**
  - **Hierarchical, region-based approach**
- **Relaxation labelling**
  - **Probabilistic, learning approach**
- **Segmentation as optimisation**

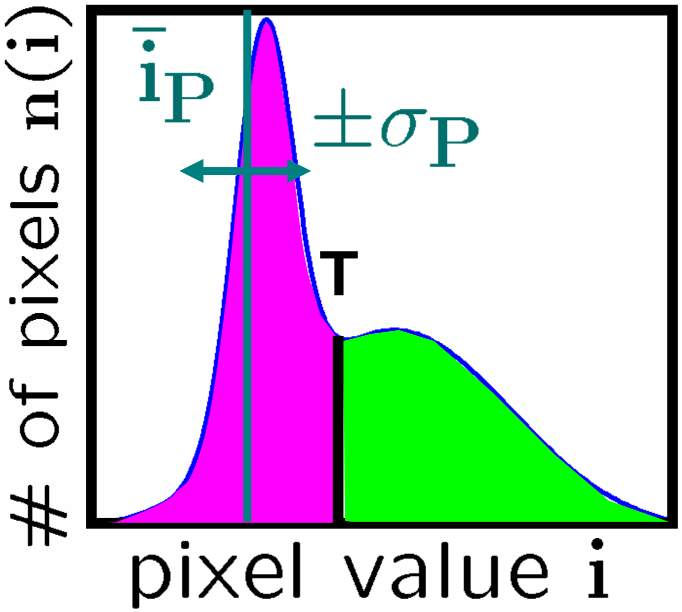
Automatic Threshold Selection

Automatic Thresholding: GMM



- Assume scene mixture of substances, each with normal/gaussian distribution of possible image values
- Minimum error in probabilistic terms
- But mixture of gaussians not easy to find
- Doesn't always fit actual distribution

Automatic Thresholding: Otsu's Method



Mean across purples:

$$\bar{i}_P = \frac{1}{N_P} \sum_{i=0}^{T} i \times n(i)$$

Variance for purples:

$$\sigma_P^2 = \frac{1}{N_P} \sum_{i=0}^{T} n(i) \left[i - \bar{i}_P \right]^2$$

Choose T to minimize:

$$N_P \sigma_P^2 + N_G \sigma_G^2$$

- **Extend to multiple classes**

3

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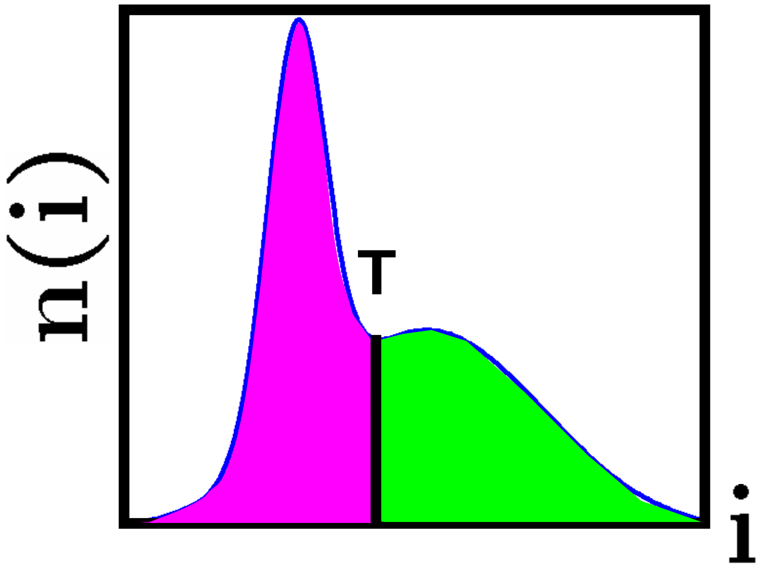
Automatic Thresholding: Max Entropy



For two sub-populations:

$$p_P(i) = \frac{n(i)}{N_P}, \quad i < T,$$

$$p_G(i) = \frac{n(i)}{N_G}, \quad i \geq T.$$

$$\boxed{\text{Entropy: } -\sum p \ln p}$$

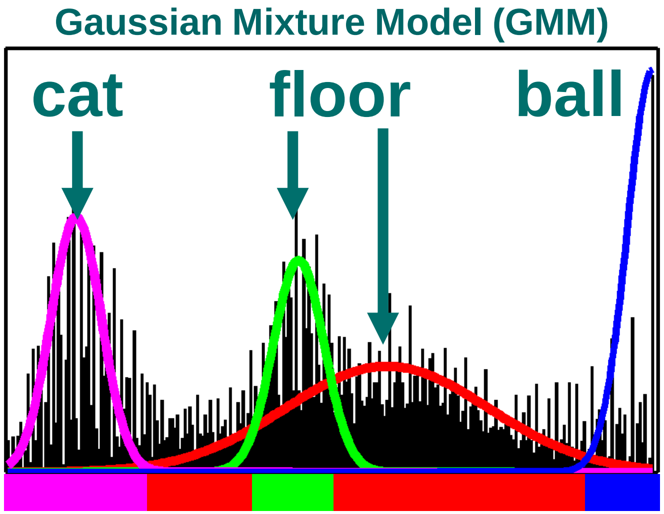
Two Entropies:

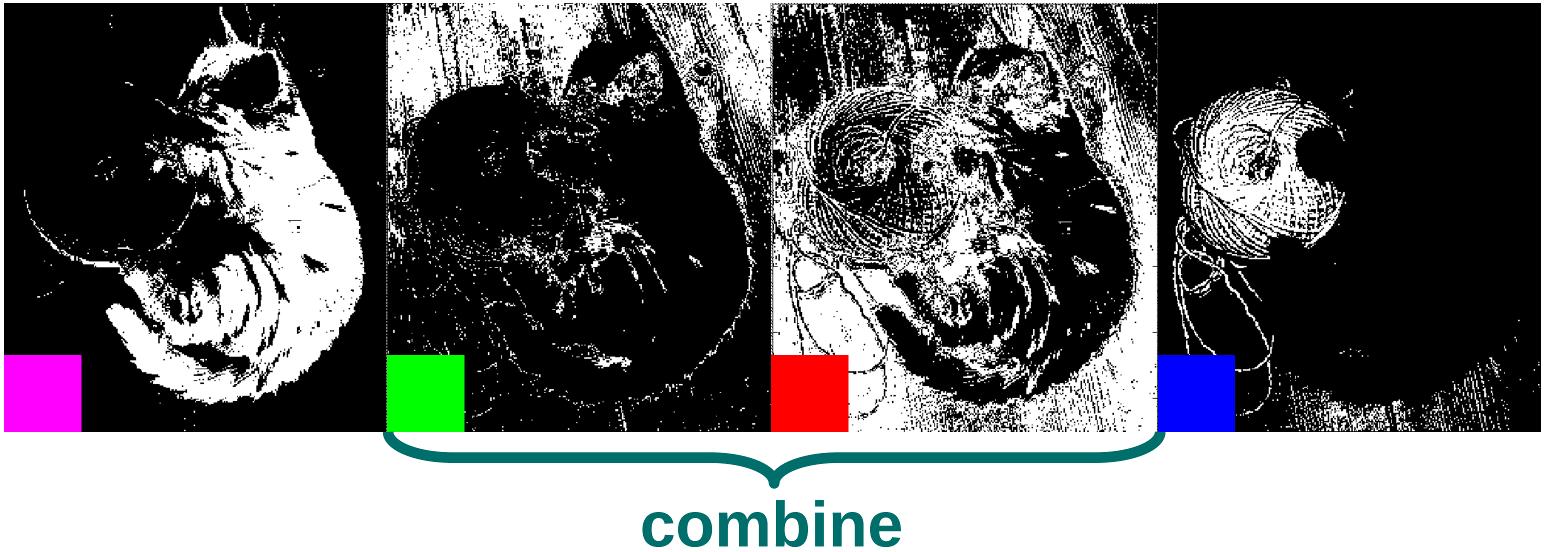
$$H_P = -\sum_{i<T} p_P(i) \ln p_P(i) \;\&\; H_G = -\sum_{i\geq T} p_G(i) \ln p_G(i)$$

$$\boxed{\text{Minimise: } H_G + H_P \text{ to find } T.}$$

- **Makes two sub-populations as peaky as possible**

Automatic Thresholding: Example





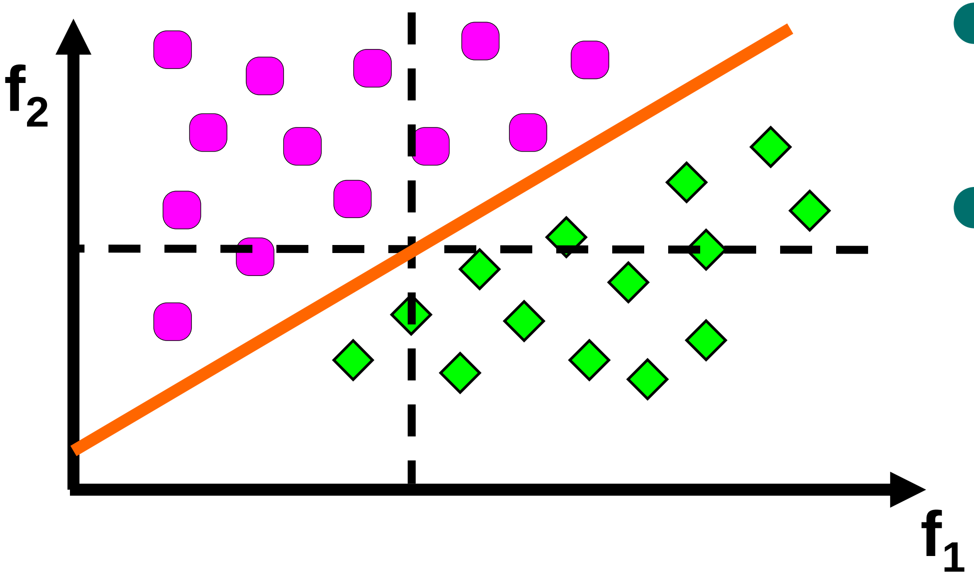
Automatic Thresholding: Summary

- Geometric shape of histogram (bumps, curves etc)
  - Algorithm or just by inspection
- Statistics of sub-populations
  - Otsu & variance
  - Entropy methods
- Model-based methods:
  - Sum of gaussians, gaussians & partial voluming etc.
- Detailed comparative evaluations for 40 methods
  - Sezgin M, Sankur B; Survey over image thresholding techniques and quantitative performance evaluation.
    Journal of Electronic Imaging, 13(1): pages 146-168, (2004).
- Fundamental limit on effectiveness:
  - Never be perfect if distributions overlap (two objects, shared colour!)
- Whatever method, need further processing

Multi-Spectral Segmentation

Multi-spectral Segmentation

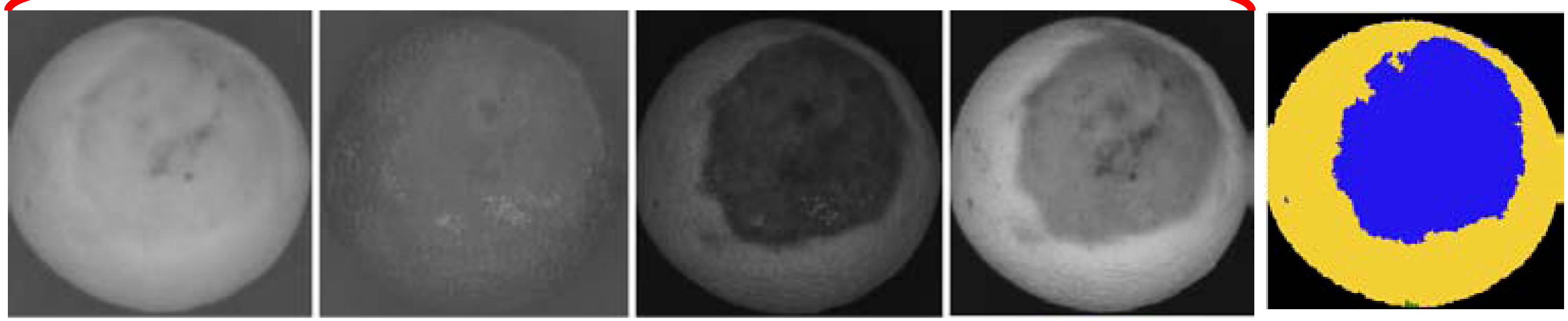
- Multiple measurements at each pixel:
  - Satellite remote imaging, various wavebands
  - MR imaging, various imaging sequences
  - Colour (RGB channels, HSV etc)
  - Multispectral imaging of historical documents (visible+IR+UV)
- Scattergram of pixels in vector space:



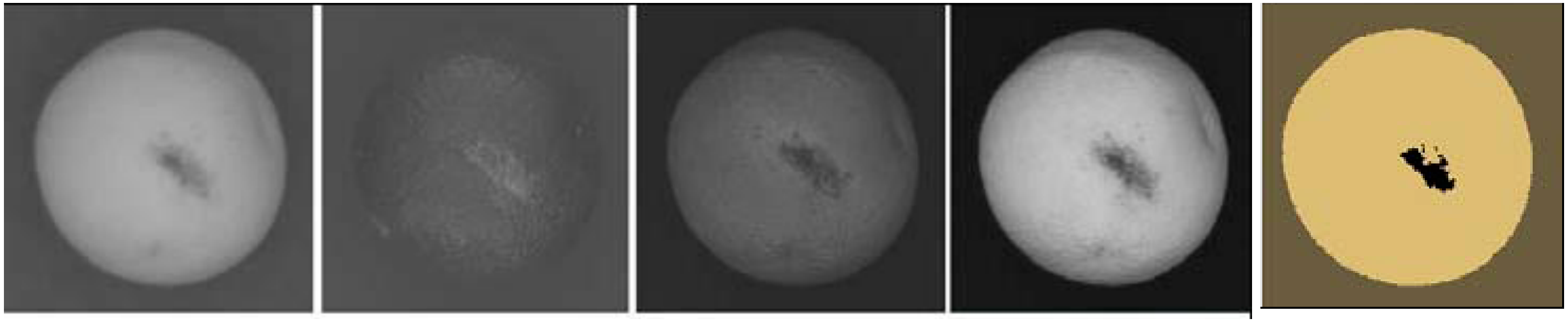
- Can’t separate using single measurement
- Can using multiple

Multi-Spectral Segmentation:Example

Spectral Bands



Over-ripe Orange



Scratched Orange

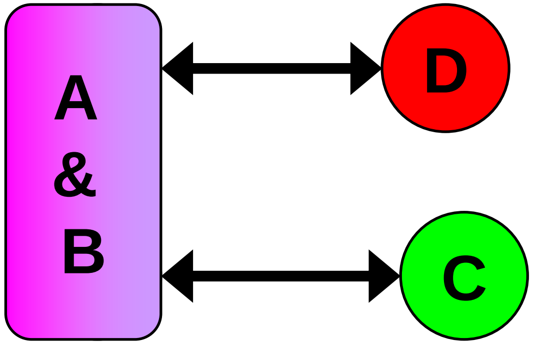
Multispectral Image Segmentation by Energy Minimization for Fruit Quality Estimation:
Martínez-Usó, Pla, and García-Sevilla, **Pattern Recognition and Image Analysis , 2005**

Split and Merge

Split and Merge/Quadtree Segmentation

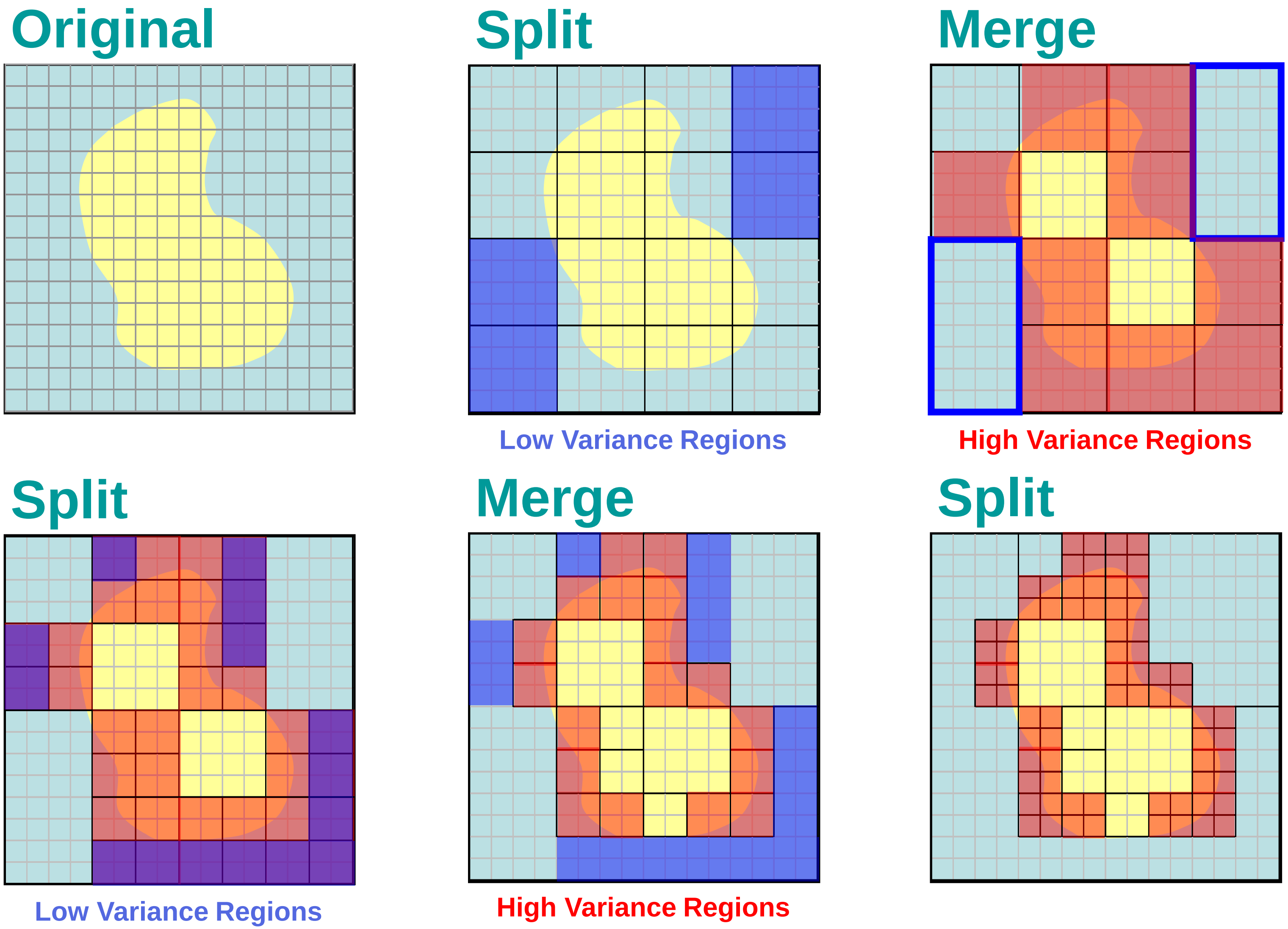
- Obvious approaches to segmentation:
  - Start from small regions and stitch them together
  - Start from large regions and split them

  Combine
- Start with large regions , split non-uniform regions
  - e.g. variance σ^2 > threshold
- Merge similar adjacent regions
  - e.g. combined variance σ^2 < threshold

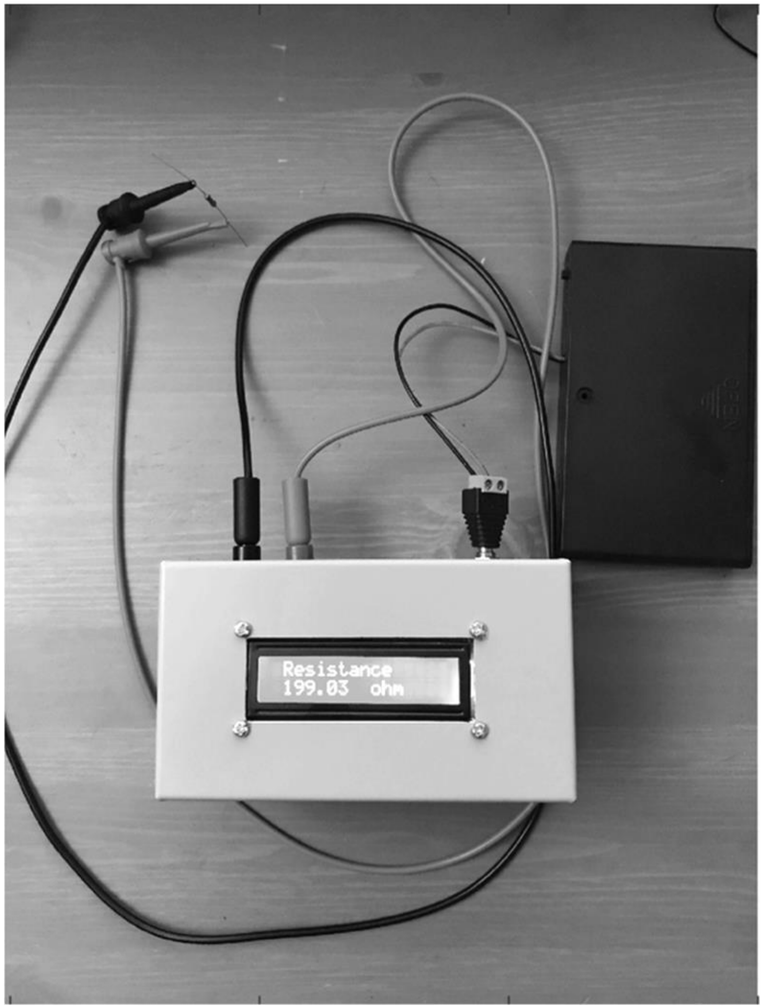


- Region adjacency graph
  - housekeeping for adjacency as regions become irregular
  - regions are nodes, adjacency relations arcs
  - simple update rules during splitting and merging

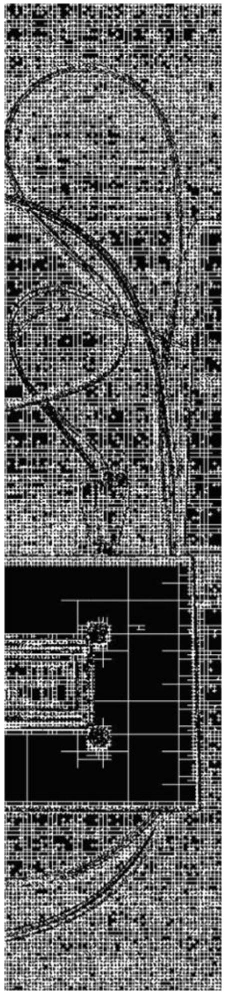
Split and Merge/Quadtree Segmentation



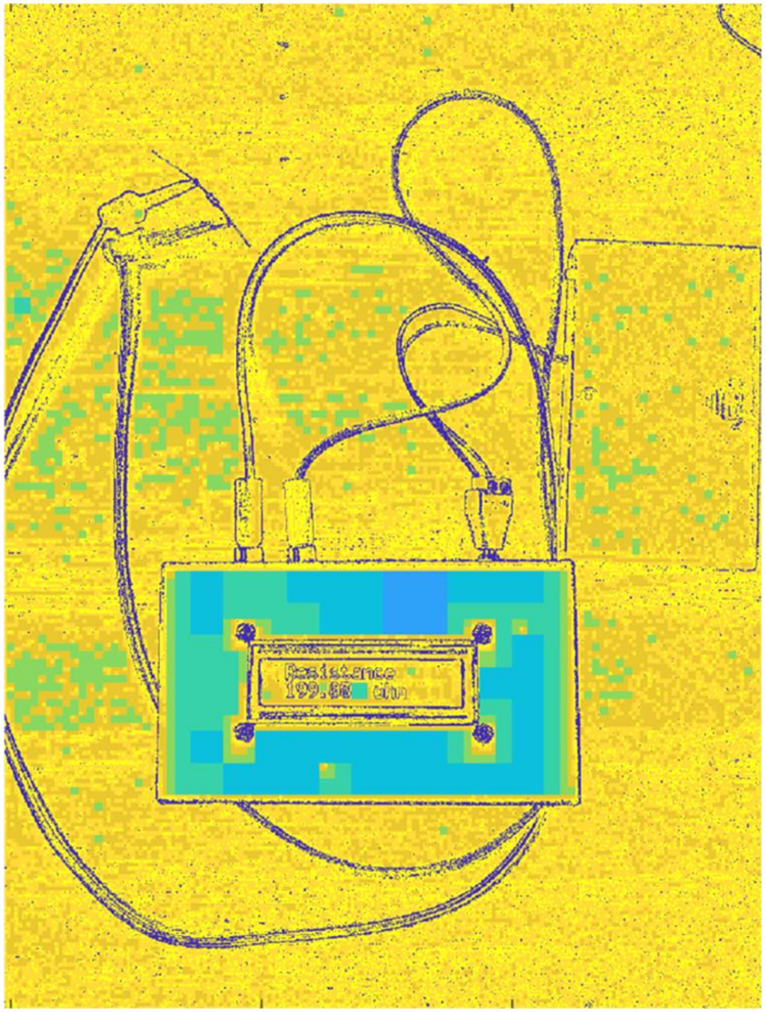
Split & Merge: Example



Original



Detail of Blocks



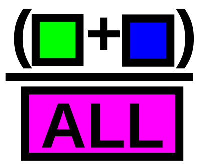
Result

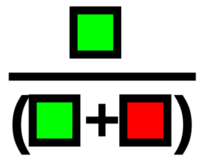
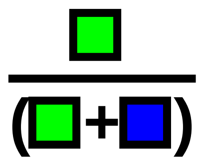
Relaxation Labelling

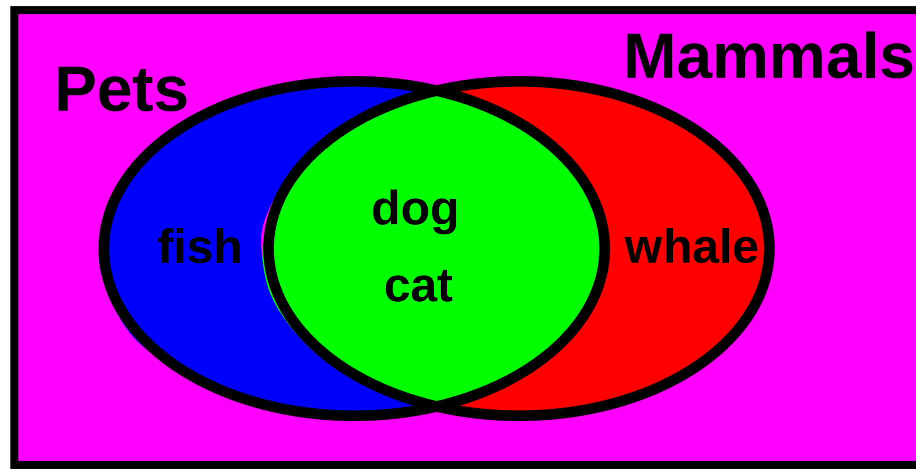
Aside: Conditional Probability

probability of A given that B is the case

$$P(A \mid B)$$

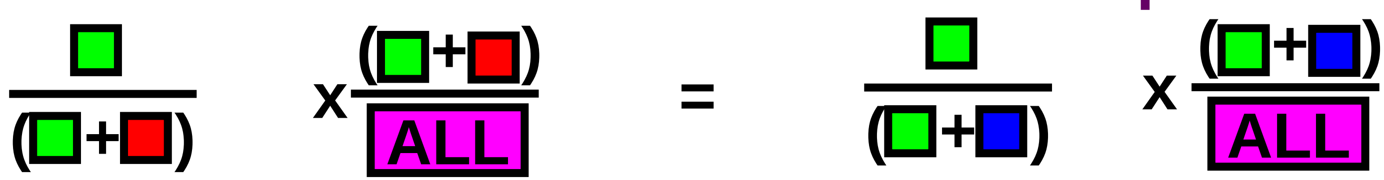
- P(pet) =  etc

- P(pet | mammal) = 
- P(mammal | pet) = 



All Animal Species

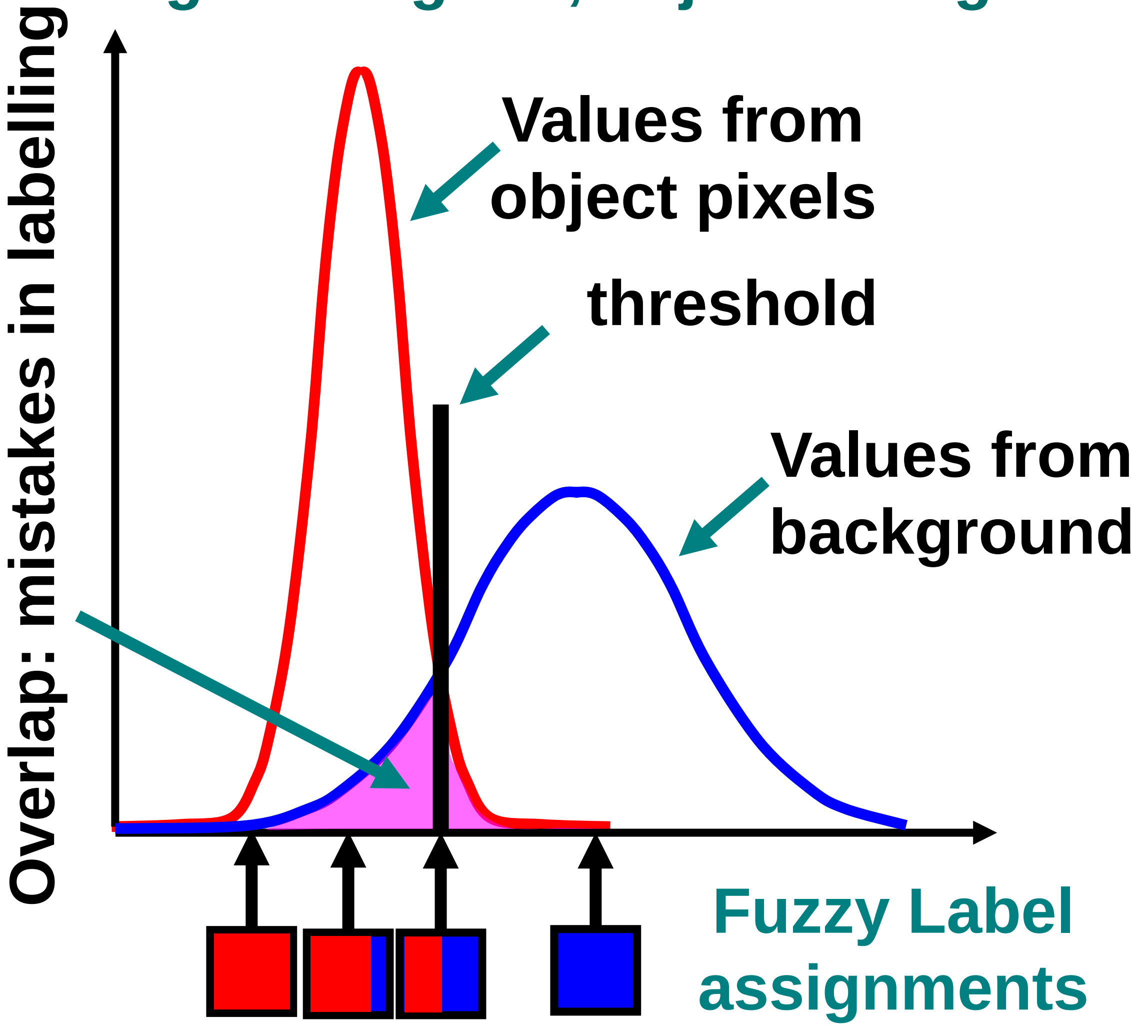
- Bayes Theorem:



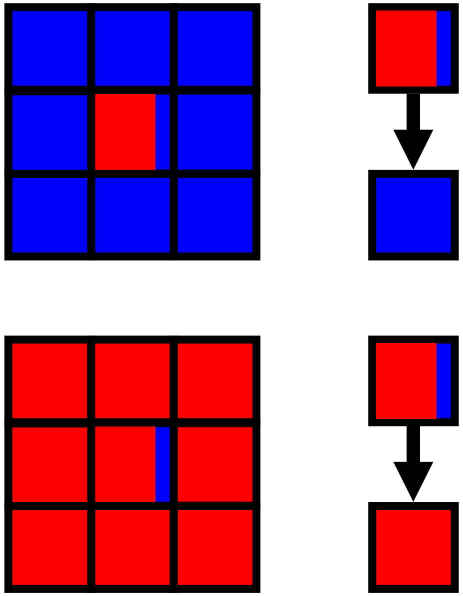
- P(pet | mammal)P(mammal) = P(mammal | pet)P(pet)

Relaxation Labelling:

- Image histogram, object/background



Context:



Context to resolve ambiguity

Relaxation Labelling

- Evidence for a label at a pixel:
  - Measurements at that pixel (e.g., pixel value)
  - Context for that pixel (i.e., what neighbours are doing)
- Iterative approach, labelling evolves
- Soft-assignment of labels:

Possible labels: $\{l_\mu : \mu = 1, \dots \mathbf{n}\}$

$\mathbf{P_i}(\mu)$: Probability that pixel i has label l_μ.

$\sum_\mu \mathbf{P_i}(\mu) \equiv 1$. normalised probability.

- Soft-assignment allows you to consider all possibilities
- Let context act to find stable solution

Relaxation Labelling

- **Compatibility:**

Pixels i and j, labels μ and ν:

no effect $\mathbf{c_{i,j}}(\mu, \nu) = 0$ **If not neighbours**

support (+ve) $\mathbf{c_{i,j}}(\mu, \mu) = \alpha$ **Neighbours & same label**

oppose (-ve) $\mathbf{c_{i,j}}(\mu, \nu) = -\alpha$ if $\mu \neq \nu$ **Neighbours & different label**

- **Contextual support for label μ at pixel *i* :**

$$\mathbf{s_i}(\mu) \propto \boxed{\sum_{\mathbf{j} \neq \mathbf{i}}} \boxed{\sum_{\nu}} \boxed{\mathbf{c_{i,j}}(\mu, \nu)} \boxed{\mathbf{P_j}(\nu)}$$

look at all other pixels

degree of compatibility

all possible labels & how strong

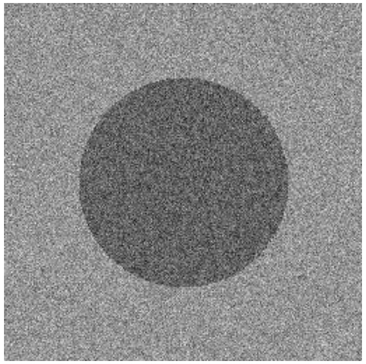
Relaxation Labelling:

- Update soft labelling given context:

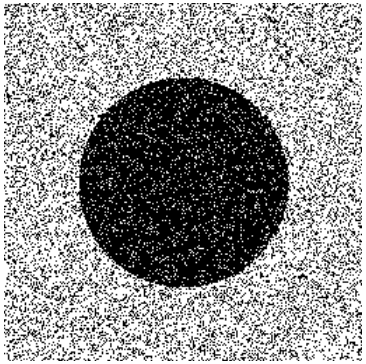
$$\mathrm{P_i}(\mu) \Leftarrow \mathrm{A_i P_i}(\mu)(1 + \mathrm{s_i}(\mu))$$

$\mathrm{A_i}$ chosen so sums to 1 at i.

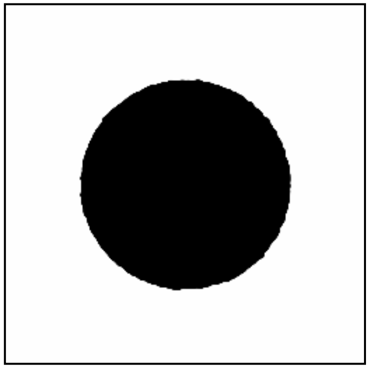
- The more support, more likely the label
- Iterate



Noisy Image



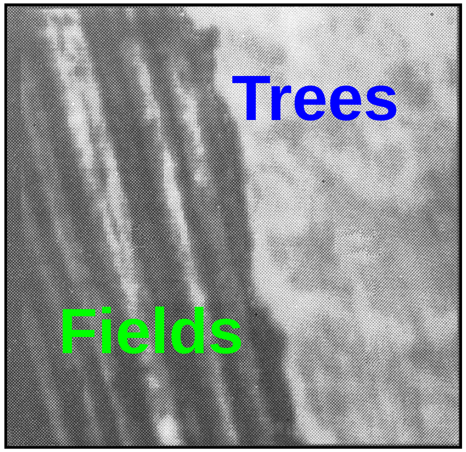
Threshold labelling



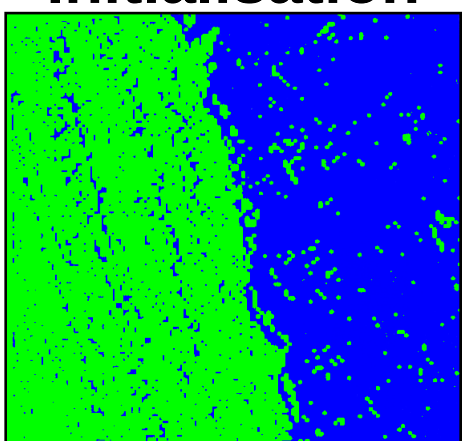
After iterating

Relaxation Labeling:

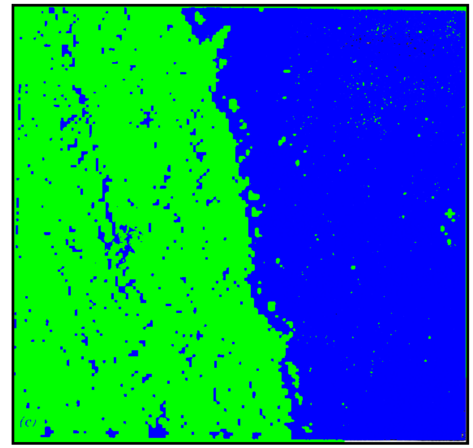
- Value of α alters final result



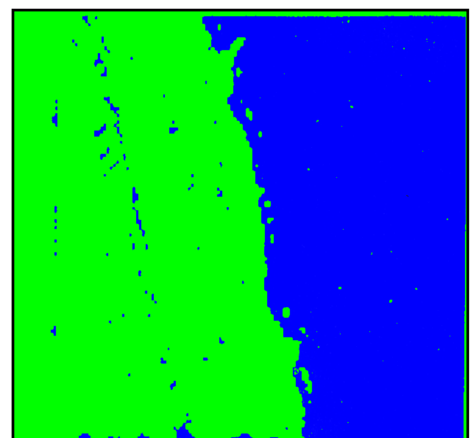
Initialisation



α = 0.75



α = 0.90



Segmentation as Optimisation

Segmentation as Optimisation

Image: $\mathcal{I}$, value at pixel i: $\mathcal{I}(i)$

Label Image: L, label at pixel i: $L(i)$

Label configuration in neighbourhood of i: $l(i)$

- **Maximise probability of labelling given image:**

$$P(L|\mathcal{I}) = \prod_i P(L(i)|\mathcal{I}(i))\,P(L(i)|l(i))$$

label at i given value at i **label at i given labels in neighbourhood of i**

- **Re-write by taking logs, minimise cost function:**

$$C(L,\mathcal{I}) = \sum_i \left[-\log P(L(i)|\mathcal{I}(i)) - \log P(L(i)|l(i))\right]$$

label-data match **label consistency**

- **How to find the appropriate form for the two terms?**
- **How to find the optimum?**

Segmentation as Optimisation

$P(L(i)|l(i))$

label consistency

$P(L(i)|\mathcal{I}(i))$

label-data match

- Exact form depends on type of data
- Histogram gives: $p(\mathcal{I}(i))$
- Model of histogram $P(L(i)|\mathcal{I}(i))$

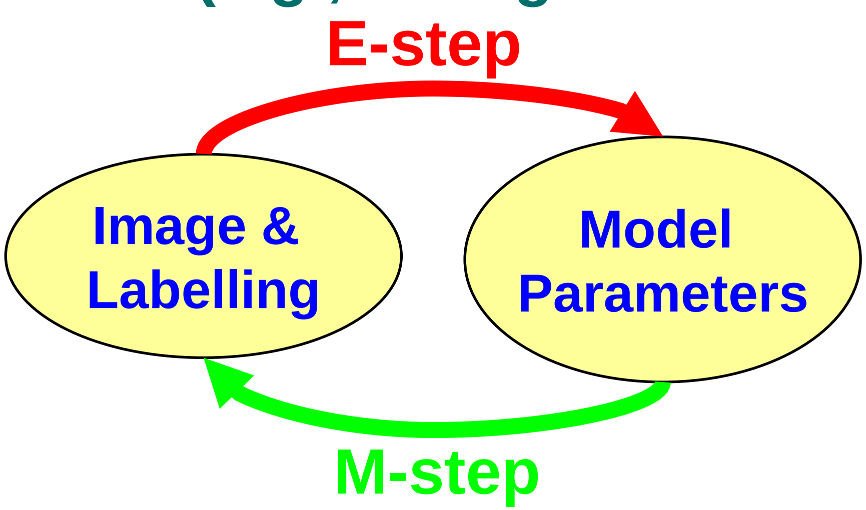
(e.g., sum of gaussians, relaxation case)

Learning approach:

- Explicit training data (i.e., similar labelled images)
- Unsupervised, from image itself (e.g., histogram model):

Expectation/Maximization

- Given labels, construct model
- Given model, update labels
- Repeat

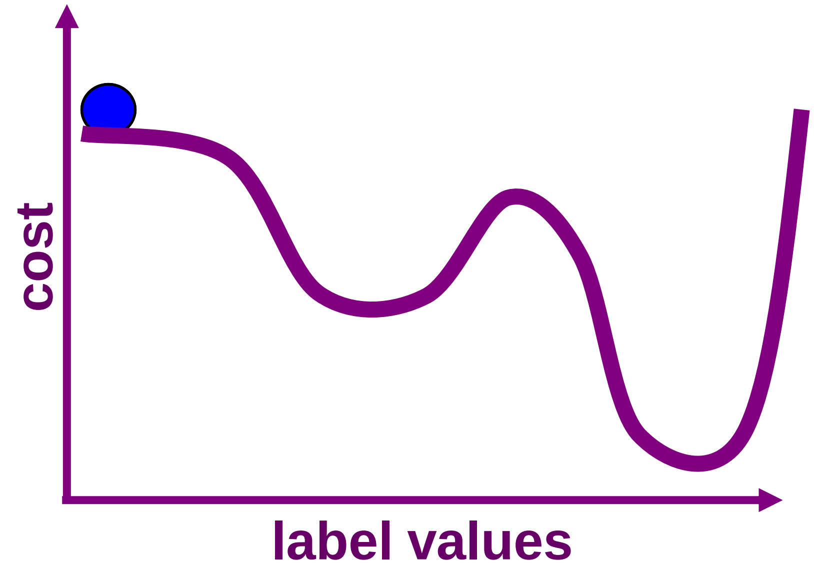


Segmentation as Optimisation

- **General case:**

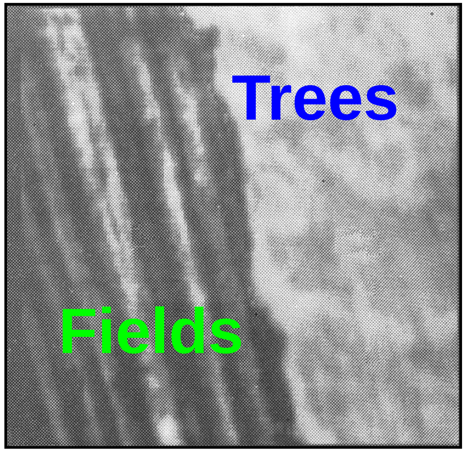
$$\text{Cost function: } C(L, \mathcal{I}) = \boxed{\text{label-data match term}} + \boxed{\text{label consistency}}$$

- **High-dimensional search space, local minima**
- **Analogy to statistical mechanics**
  - **crystalline solid finding minimum energy state**
  - **stochastic optimisation**
  - **simulated annealing**
- **Search:**
  - **Downhill**
  - **Allow slight uphill**

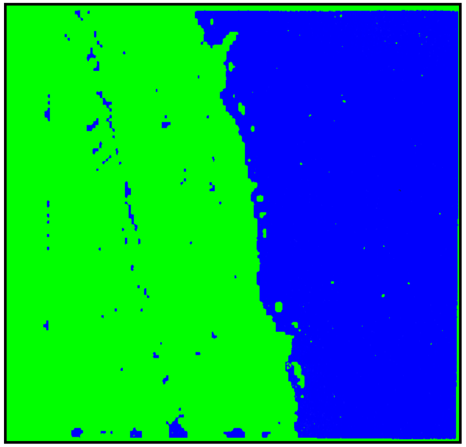


Segmentation as Optimisation

$\alpha = 0.90$



Original



Relaxation

Optimisation