Segmentation of Curvilinear Objects using a Watershed-Based Curve Adjacency Graph

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A classical segmentation framework

- Compute gradient norm image

  objects' contours are crest lines

- Apply a morphological closing

  when *no prior* info are known about objects; small local minima are removed

- Run the watershed transform (WST)

  an over-segmentation is obtained

- Extract the region-adjacency graph (RAG)

  the image is described by a structure

- Perform region merging
  as a Markov random field (MRF) labeling

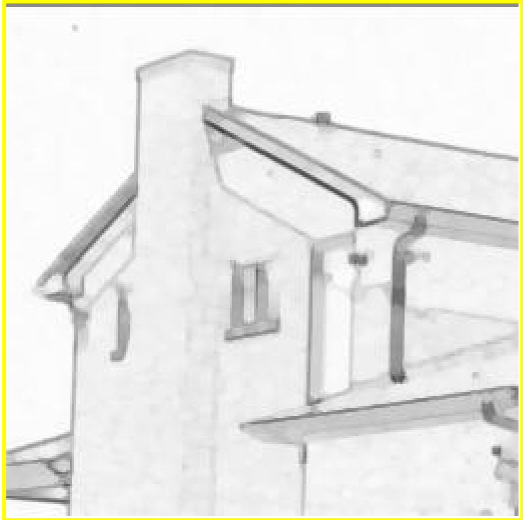
  final segmentation results from a global optimization process

A classical segmentation framework

Original

gradient norm image (GMI)

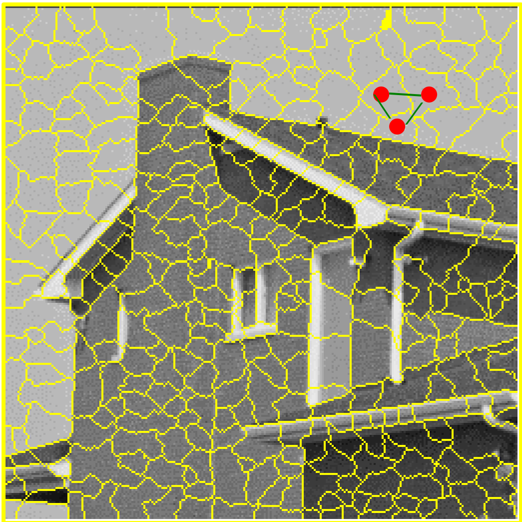
GMI closed



Morphological closing ensures that regions have a sufficient size to get relevant statistical features

A classical segmentation framework

RAG defined upon WST's result => input of a Markovian relaxation



"WST+RAG+MRF" framework:

- a region-oriented approach
- efficient
- adaptable
- general
- leads to effective results (global optimization)
- reliable

What about curvilinear objects?

- In the "WST+**R**AG+MRF" framework:
  - objects to be segmented are **regions**
  - GMI is a "potential" image that highlights contours

    contours *are* curvilinear objects!
  - morphological closing is used to simplify data
  - contours are included in the watershed line

    the WST *is* a curvilinear object extractor!
  - a RAG is defined to get structured data
  - MRF on RAG is a powerful tool to process an over-segmentation

so we propose to adapt the "WST+RAG+MRF" framework to the segmentation of curvilinear objects...

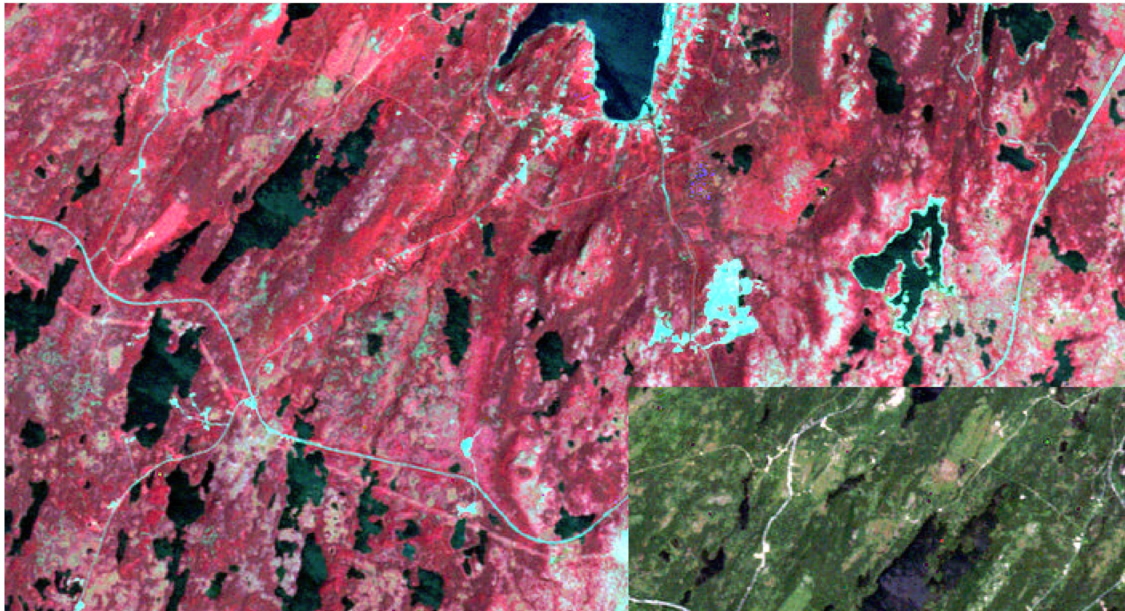
What about curvilinear objects?

- In the "WST+**C**AG+MRF" framework:
  - objects to be segmented are **curvilinear**
  - we need a "potential" image that highlights objects

  - morphological closing can also be used to simplify data
  - curvilinear objects are included in the watershed line

  - a curve adjacency graph (CAG) is defined to get structured data
  - MRF on CAG is a powerful tool to process an over-segmentation

Case study -- original image



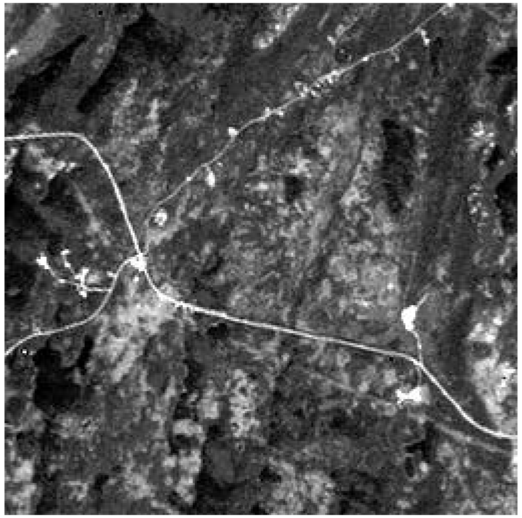
IR channels

RGB channels

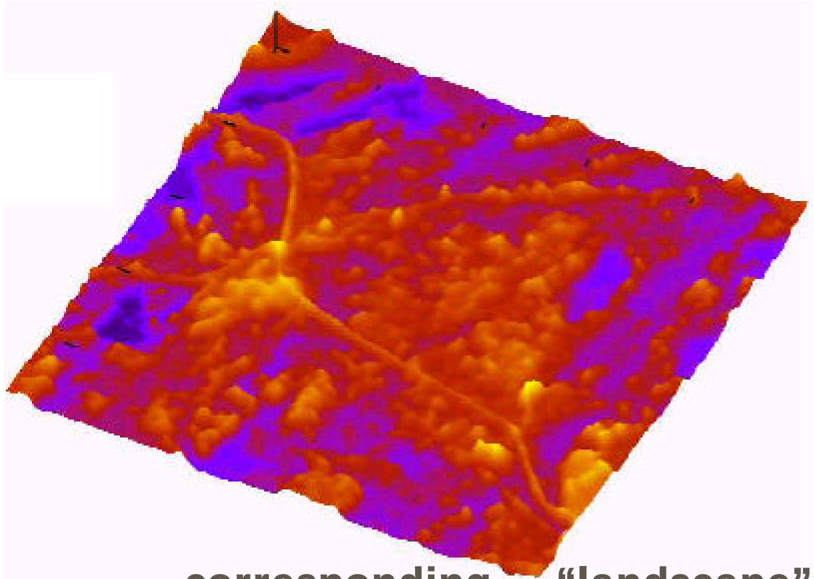
Landsat-7 image (25m res.)

Case study -- potential image

potential image crest lines *should* include objects to be segmented



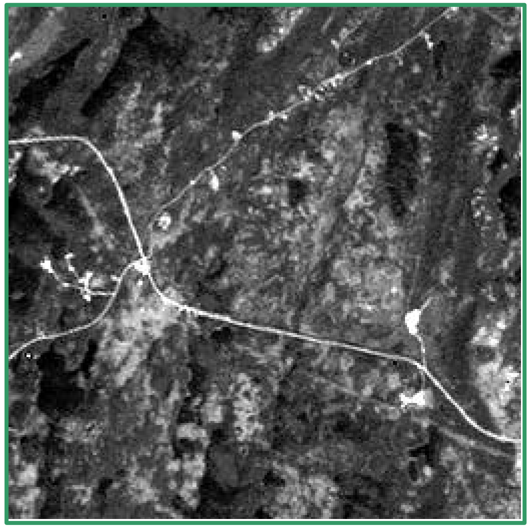
green channel



corresponding "landscape"

Case study -- WST (without closing first)

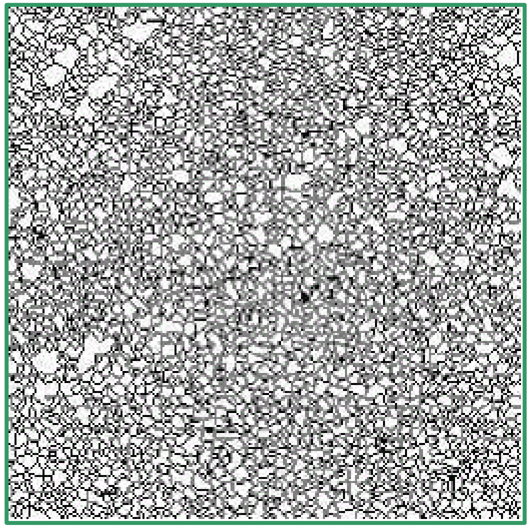
Potential image



☜ one local minimum

gives one region ☞

Watershed line

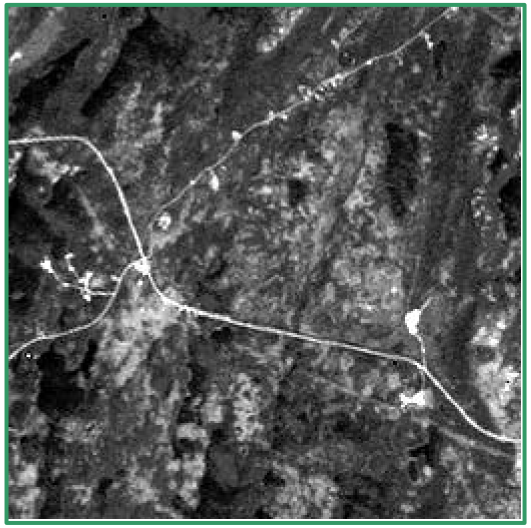


object to be segmented is somewhere (but where?) ☹

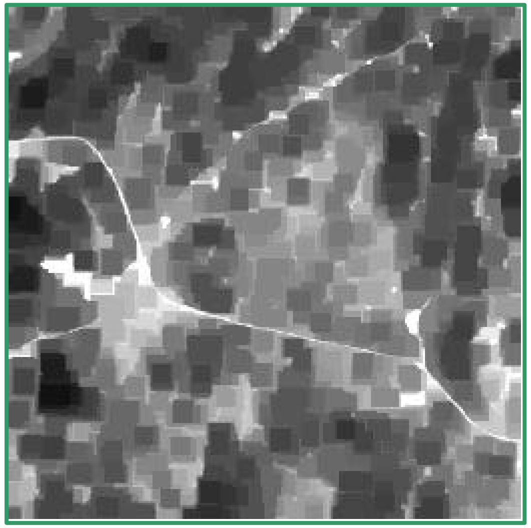
too many elementary pieces of watershed line
actually too many local minima in the potential image

Case study -- closing + WST

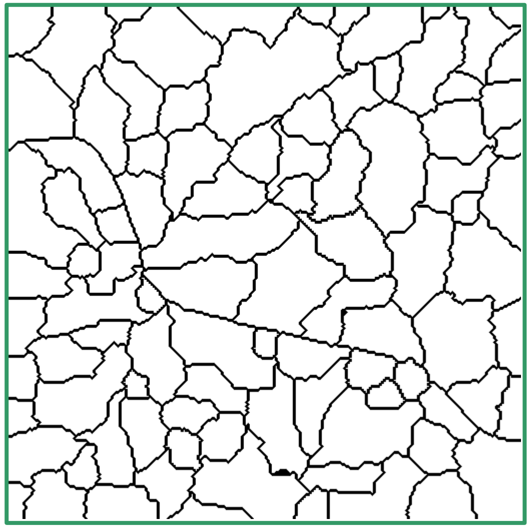
Potential image



“Regular” closing



Watershed line



with the “regular” morphological closing, crest lines are shifted ☹

whatever the shape of the structural element

this artifact increases along with the size of the struct.elt.

Case study -- attribute closing

B is a binary image, p is a pixel of B

B_i is a connected component of B

$B_{i(p)}$ is the connected component of B containing p

a is an attribute of a connected component (e.g., its area)

λ is a positive value

binary attribute opening: $g_l^a(B) = \{ p \mid a(B_{i(p)}) > \lambda \}$

or: $g_l^a(B) = \bigcup \{ B_i \mid a(B_i) > \lambda \}$

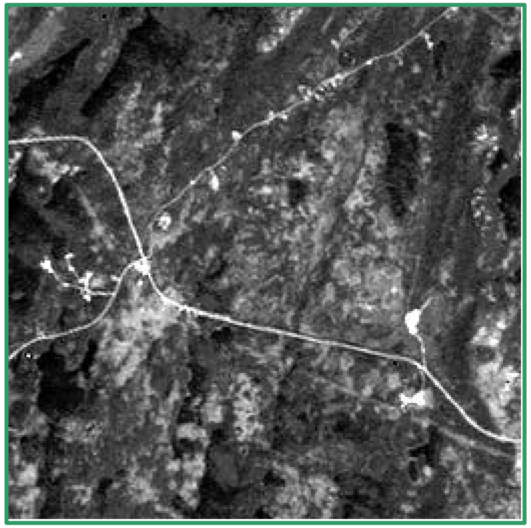
binary attribute closing: $y_l^a(B) = \mathrm{inv}(g_l^a(\mathrm{inv}(B)))$

I is a gray-level image

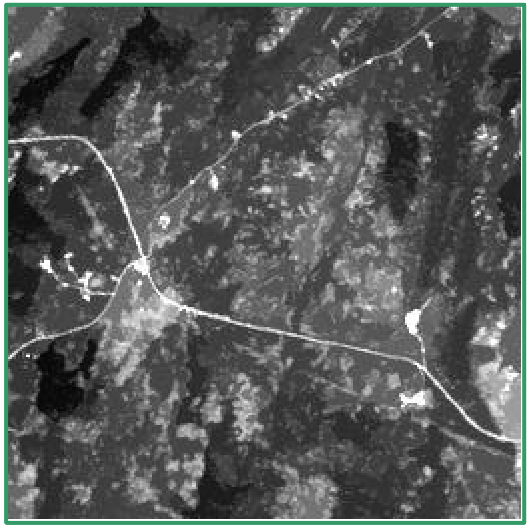
gray-level attribute opening: $g_l^a(I) = \mathrm{merge}_l(g_l^a(\mathrm{split}_l(I)))$

Case study -- area closing + WST

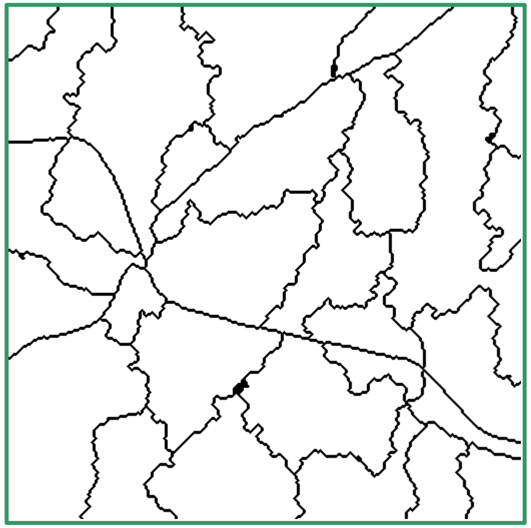
Potential image



MM area closing



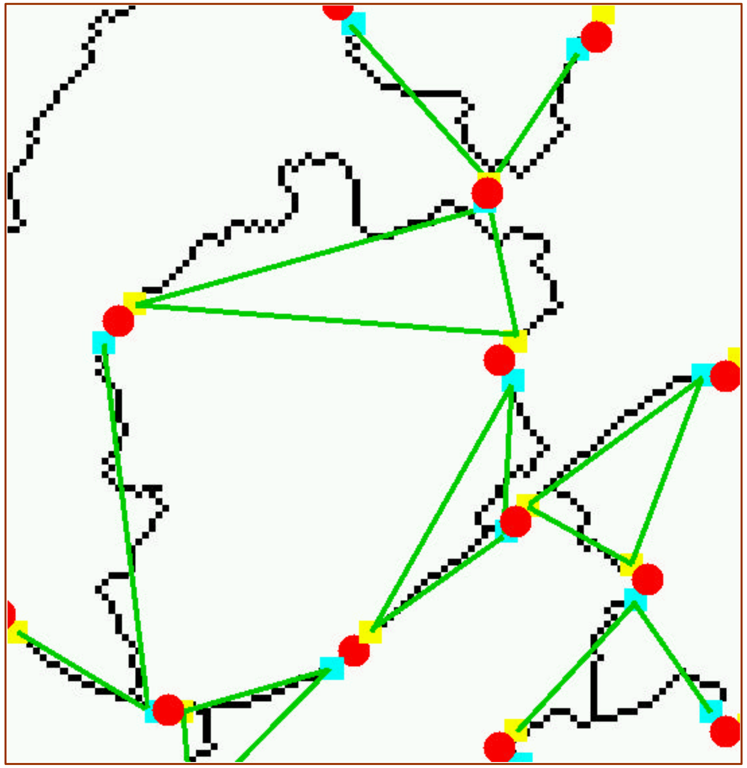
Watershed line



area closing removes local minima without shifting crest lines ☺

threshold value λ ensures a minimal region area
O(N log N) complexity [Meijster and Wilkinson, 1999]

Case study -- Curve adjacency graph



CAG:

- node = piece of watershed line separating two basins (shed)
- edge = connection between two sheds

- node attributes: length, mean curvature, mean curvature deviation, mean potential, surrounding contrast, etc.
- edge attributes: spatial continuity, etc.

Case study -- Markov random fields

X is the solution MRF; a shed s should be assigned a Boolean label:

$$x_s = \text{true} \mid \text{false}$$ (meaning object or not)

Y is the observation MRF:

y_s encloses attributes of CAG shed s

Hypothesis:

$$P(\, Y = y \mid X = x \,) \;=\; \Pi_s \; P(\, Y_s = y_s \mid X_s = x_s \,)$$

$$P(\, X = x \,) \;=\; \Pi_s \; P(\, X_s = x_s \mid X_{N(s)} = x_{N(s)} \,)$$

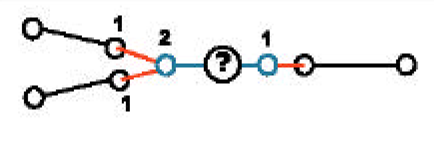
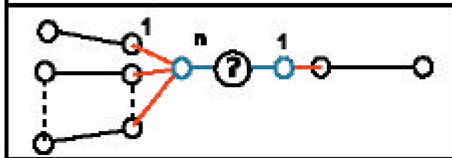
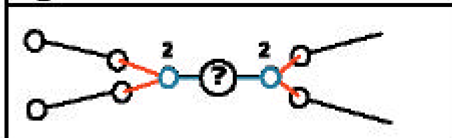
Bayesian solution (e.g., given by the Metropolis algorithm):

$$\arg\,\max_x P(\, X = x \mid Y = y \,) \;=\; \arg\,\min_x \big(\, \underbrace{U_d(\, y_s \,,\, x_s \,)}_{\text{data term}} + \underbrace{U_c(\, x_s \,,\, x_{N(s)} \,)}_{\text{contextual term}} \,\big)$$

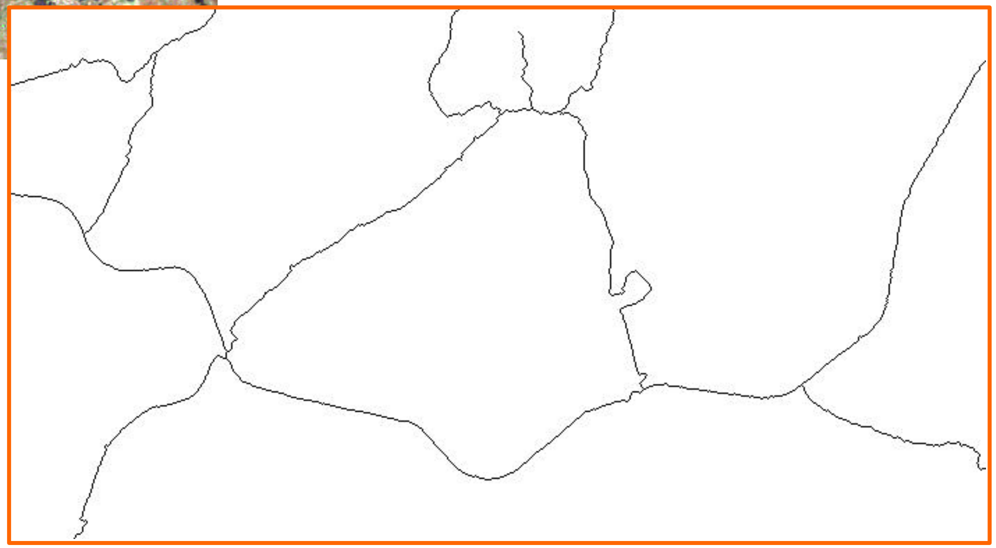
Case study -- energy terms in MRF

- Both energy terms depend on your problem...
- Data term:
  - geometry of a piece of object
  - its environment in input image
- Contextual term:
  - global object geometry

for instance:

Configuration	Probability	U
	High	0
	Medium	0.2
	Low	1
	Low	1

Case study -- results



original image: 2.10^6 pixels
1,7GHz PC running GNU/Linux
processing time: **20 s**

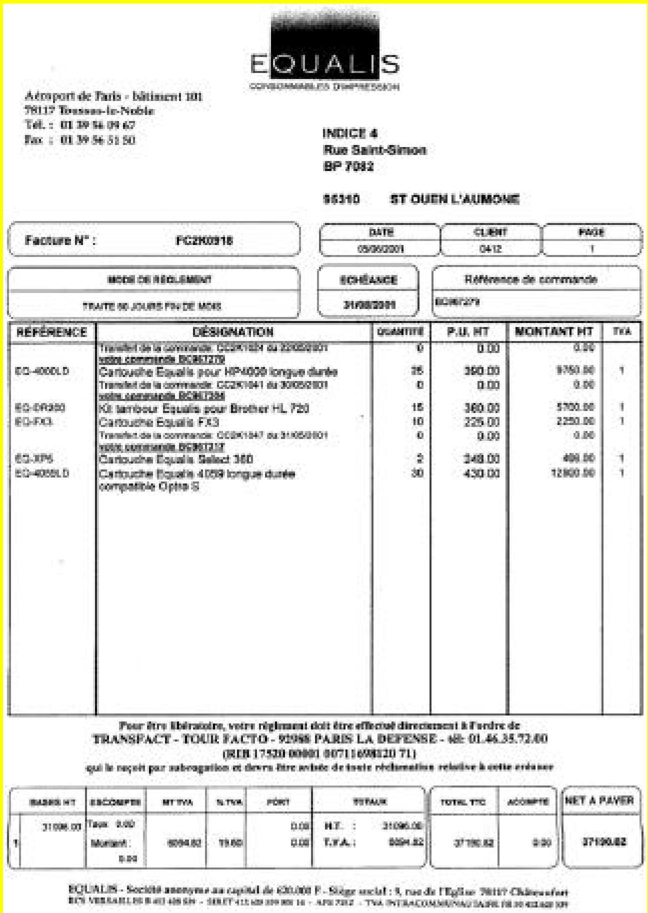
Drawback

watershed line cannot invent some data

=> some bad connections or disconnections can appear

Other applications

form segmentation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TRAITE 60 JOURS FIN DE MOIS	31/08/2001	BC067279

RÉFÉRENCE	DÉSIGNATION	QUANTITÉ	P.U. HT	MONTANT HT	TVA
	Transfert de la commande: CC2K1024 du 22/05/2001 votre commande BC067279	0	0.00	0.00	
EQ-4000LD	Cartouche Equalis pour HP4000 longue durée	25	390.00	9750.00	1
	Transfert de la commande: CC2K1041 du 30/05/2001 votre commande BC067284	0	0.00	0.00	
EQ-DR350	Kit tambour Equalis pour Brother HL 720	15	380.00	5700.00	1
EQ-FX3	Cartouche Equalis FX3	10	225.00	2250.00	1
	Transfert de la commande: CC2K1047 du 31/05/2001 votre commande BC067217	0	0.00	0.00	
EQ-XP6	Cartouche Equalis Select 300	2	249.00	498.00	1
EQ-4059LD	Cartouche Equalis 4059 longue durée compatible Optra S	30	430.00	12900.00	1

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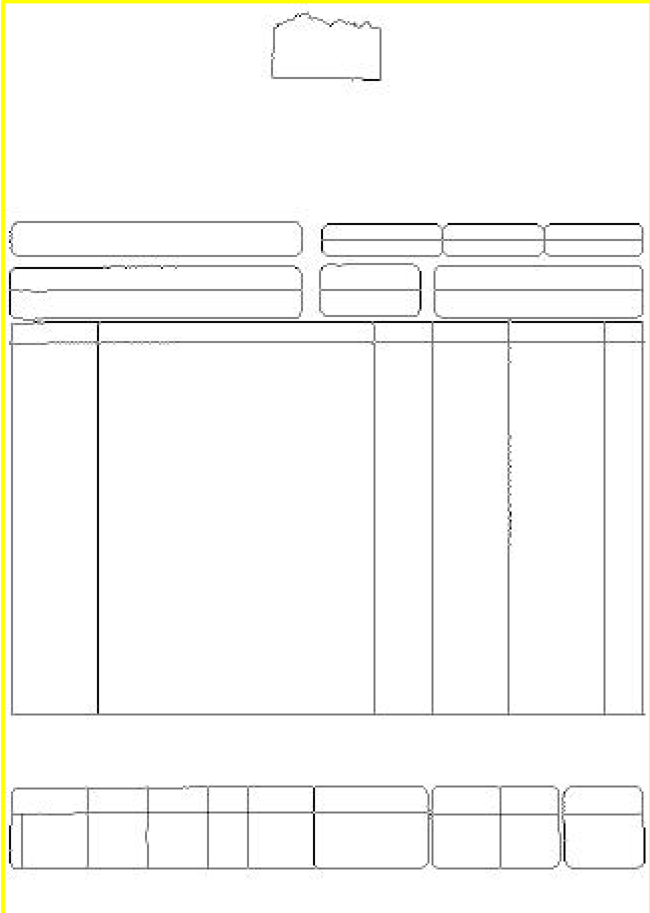
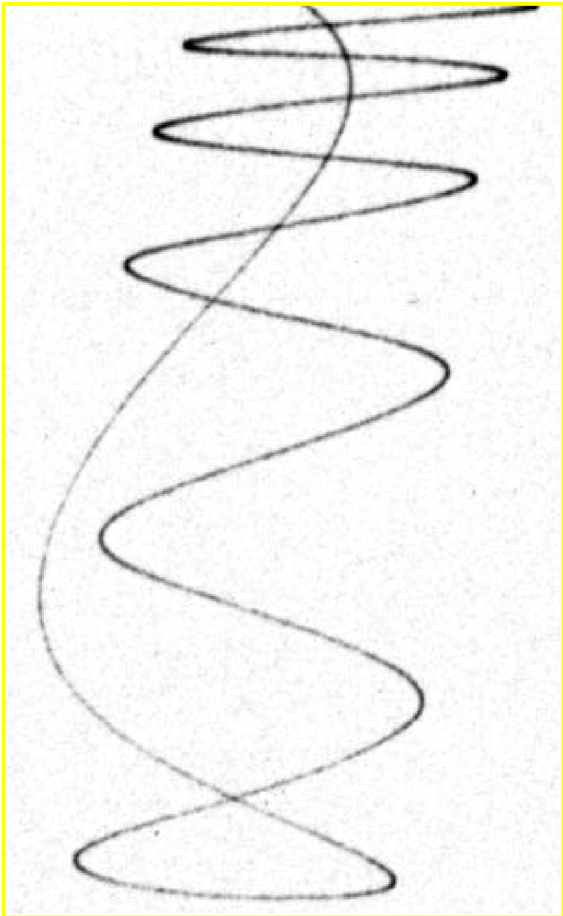
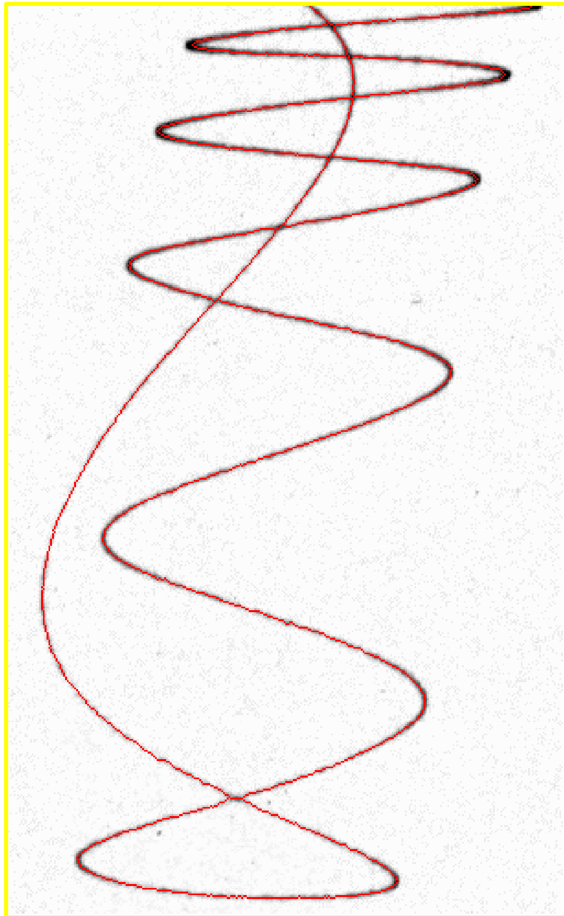


Other applications

signal tracking





Other applications

region segmentation (!)

Conclusion

- An efficient framework to segment curvilinear objects
- Highly adaptable through:
  - potential image definition
  - Markov random fields parameterization
- Perspectives:
  - numerous applications
  - multi-scale approach (thanks to attribute closing properties)

Extra information

- Source code available from

  `http://www.lrde.epita.fr`

- Developed using Olena:
  - our generic image processing library
  - free software under the GNU Public Licence (GPL)

- Contact:

  `thierry.geraud@lrde.epita.fr`

thanks for your attention; any question?