Spatial Information

(in Bio-Ontologies)

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Outline

- Reasoning with spatial relations.
- Grounding ontologies in terms of spatial and material properties.
- Vague boundaries and spatial individuation

Ways to Implement Spatial Reasoning

- First-order logic inference (very hard)
- Compositional Reasoning (easy)
- DL wish Concrete Domains (may be OK)
- Modal Encoding (good)
- DL Encoding (may be good)

Compositional Reasoning

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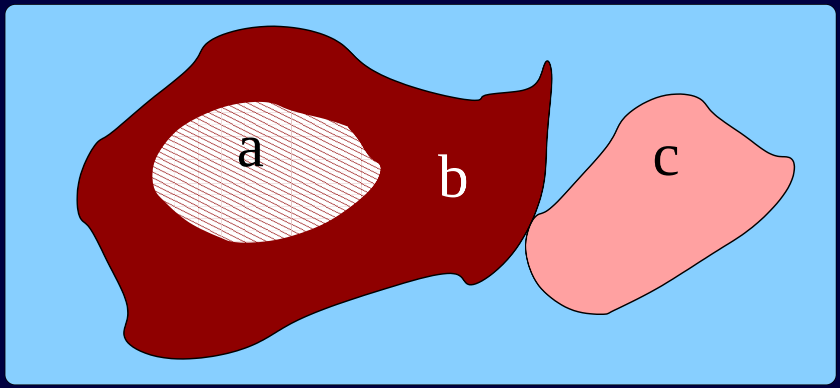
For instance among the RCC-8 relations we have:

$$\mathsf{NTPP}(a,b) \wedge \mathsf{EC}(b,c) \rightarrow \mathsf{DC}(a,c)$$



Composition Tables

Compositional inferences can be compiled into a table.

For instance, for RCC-5 we have the following table:

$R(a,b)$ \ $R(b,c)$	DR	PO	EQ	PP	PPi
DR	all poss	DR, PO, PP	DR	DR, PO, PP	DR
PO	DR, PO, PPi	all poss	PO	PO, PP	DR, PO, PPi
EQ	DR	PO	EQ	PP	PPi
PP	DR	DR, PO, PP	PP	PP	all poss
PPi	DR, PO, PPi	PO, PPi	PPi	O	PPi

Such tables allow fast look-up of compositional inferences.

Issues in the use of Compositional Reasoning

Compositional reasoning works primarily at the level of region entities rather than classes.

Thus:

- class-level spatial relations need to be given an unambiguous interpretation, in terms of the spatial extensions of class instances,

- class level consistency needs to be reduced to be reduced to consistency of exemplifying instances.

Concrete Domains

Concrete domains are an extension of Description Logic, whereby the semantics is augmented by a auxiliary ‘concrete’ domain and a number of predicates that are interpreted in terms of this domain.

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Haarslev, Lutz and Möller have specified syntax, semantics and proof theory for a DL called $\mathcal{ALCRP}(\mathcal{D})$, where $\mathcal{D}$ is a concrete domain satisfying certain conditions.

One of the concrete domains that they specify is that of subsets of the real Cartesian plane, together with the RCC-8 relations.

Modal Encoding

It turns out that topological relationships can be represented in terms of modal logic, which enables relatively effective reasoning.

The coding involves an anti-reification where spatial entities are treated as propositions, and spatial relations are represented by propositional operators.

- $\mathsf{P}(X, Y) \implies X \rightarrow Y$
- $\mathsf{NTPP}(X, Y) \implies X \rightarrow \Box Y$
- $\mathsf{DC}(X, Y) \implies \neg(X \wedge Y)$
- $\mathsf{DR}(X, Y) \implies \neg(\Box X \wedge \Box Y)$

DL Encoding

Another interesting possibility is to encode spatial reasoning directly in Description Logic (Katz and Grau 2006).

It has long been known that topological spaces can be modelled by relational structures.

If R is a *reflexive* and *transitive* relation over a space of points $\mathcal{S}$, we can define a topological closure and interior operators by:

$$\mathsf{cl}(X) = \{ p \mid \exists x[R(p,x) \wedge x \in X] \}$$

$$\mathsf{int}(X) = \{ p \mid \forall x[R(p,x) \rightarrow x \in X] \}$$

DL Translation

- cl$(X) \implies \exists R.X$
- int$(X) \implies \forall R.X$
- NE$(X) \implies X(p_x)$
- C$(X, Y) \implies C_{xy} \equiv (X \sqcap Y),\ \ C_{xy}(p_{xy})$
- O$(X, Y) \implies O_{xy} \equiv (\forall R.X \sqcap \forall R.Y),\ \ O_{xy}(p_{xy})$
- compl$(X) \implies \neg\forall R.X$
- RegCl$(X) \implies X \equiv \exists R.(\forall R.X)$

Exploitation of Spatial Reasoning

Compositional reasoning can be used to:

- infer missing information in a partial network of spatial relations.
- test consistency of spatial relationships specified by an ontology.

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To do this we need:

- a theory of spatial regions and relationships,
- an ontology of matter types,
- a formal framework for specifying complex criteria for individuation and composition of material entities.

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- use the spatial theory to individuate basic material components and characterise their properties,
- define complex entities in terms of spatial (or spatio-temporal) combinations of basic elements.
- (This process needs to be iterated for different levels of granularity, with matter types at one level being defined as composite objects at a lower level.)

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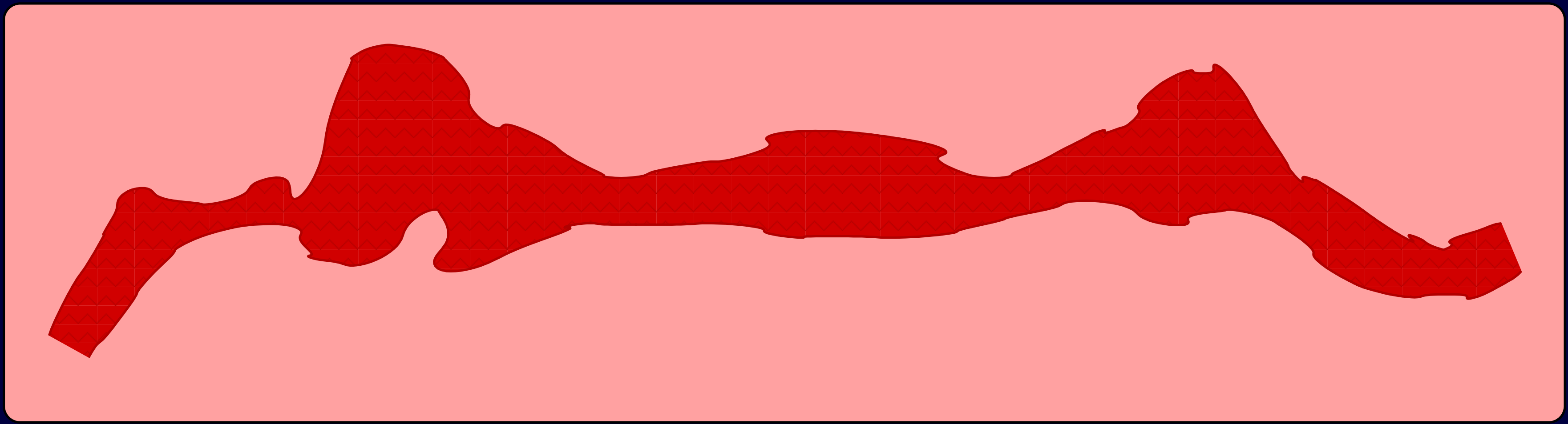
But, even vague biological boundaries are grounded and at least partially fixed by the physical structure of reality.

Can we formalise the nature of this grounding?

Individuation Example

How should we individuate the distended parts of a vessel?



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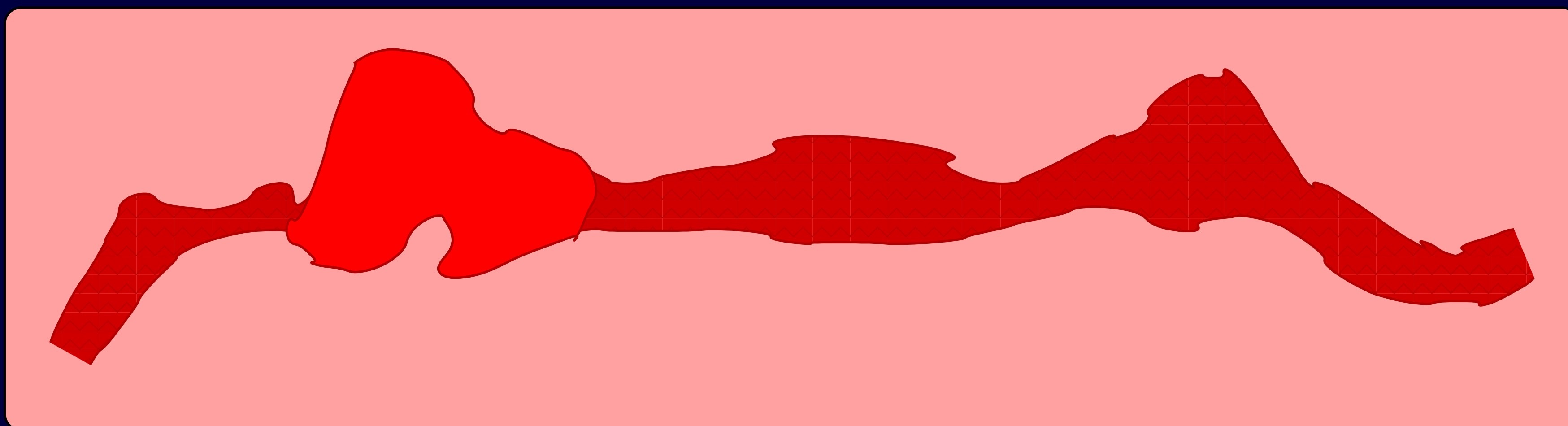

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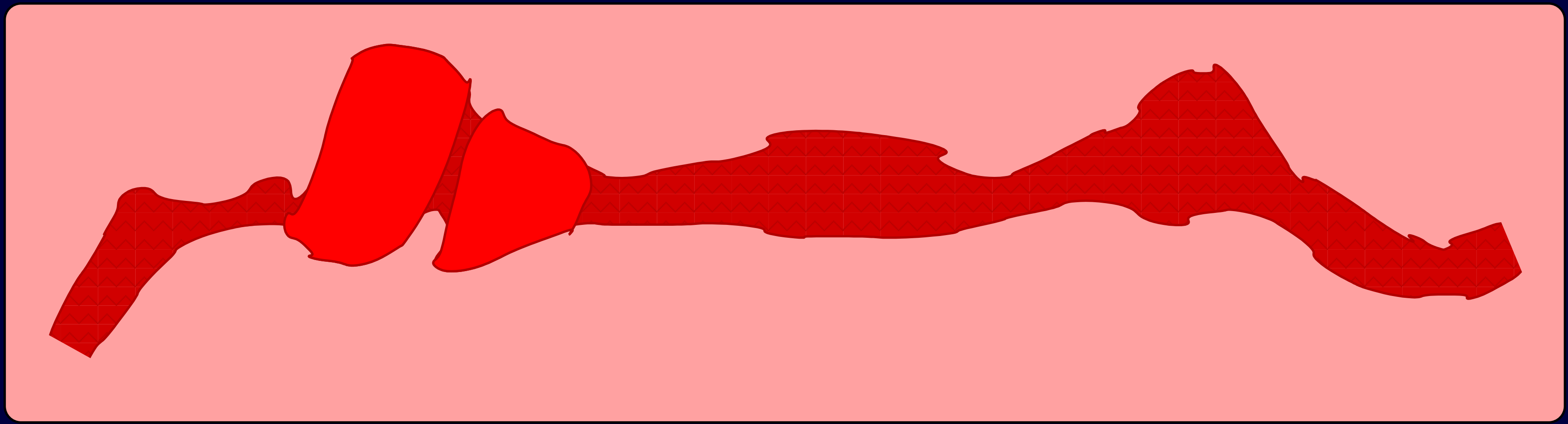
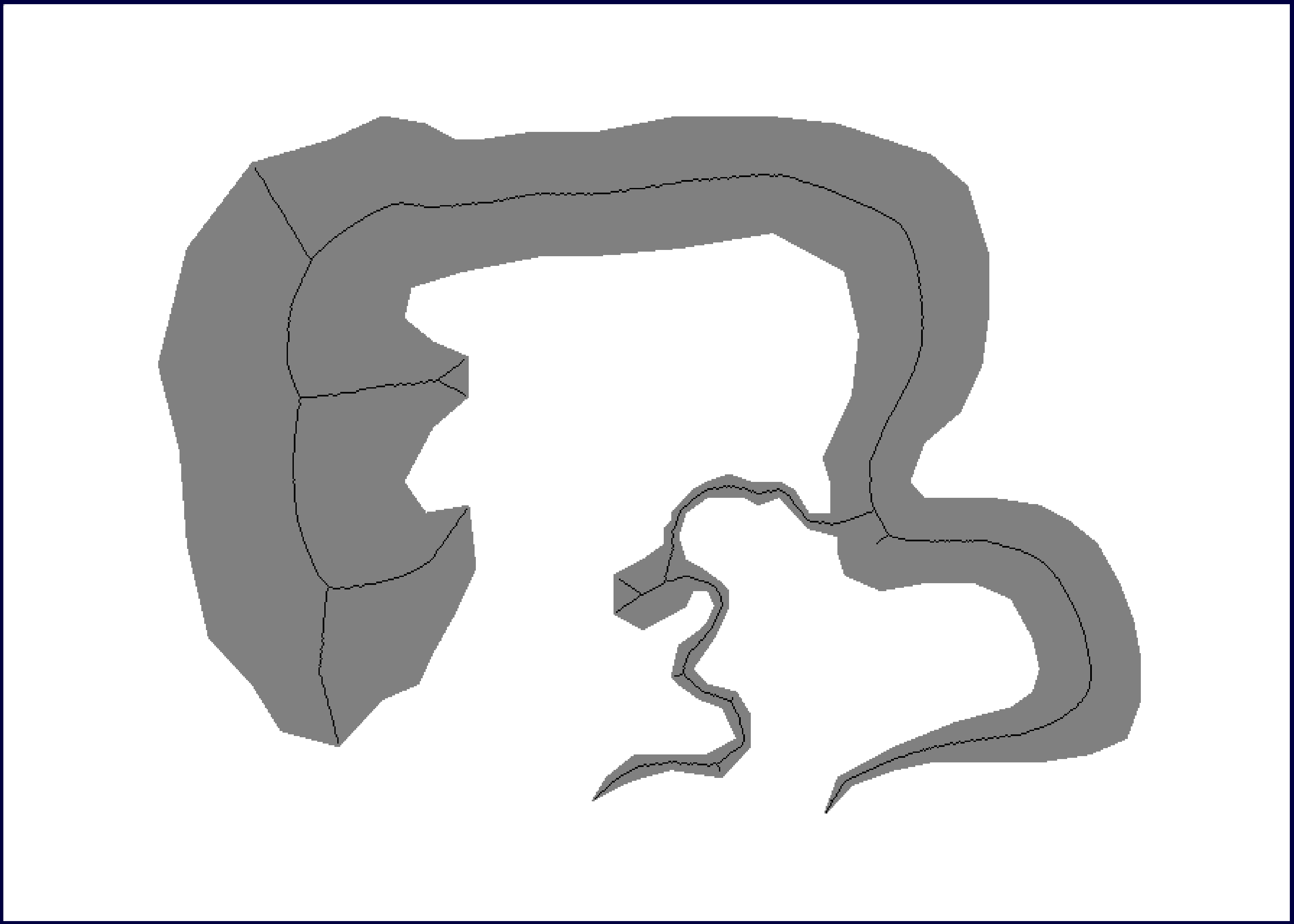
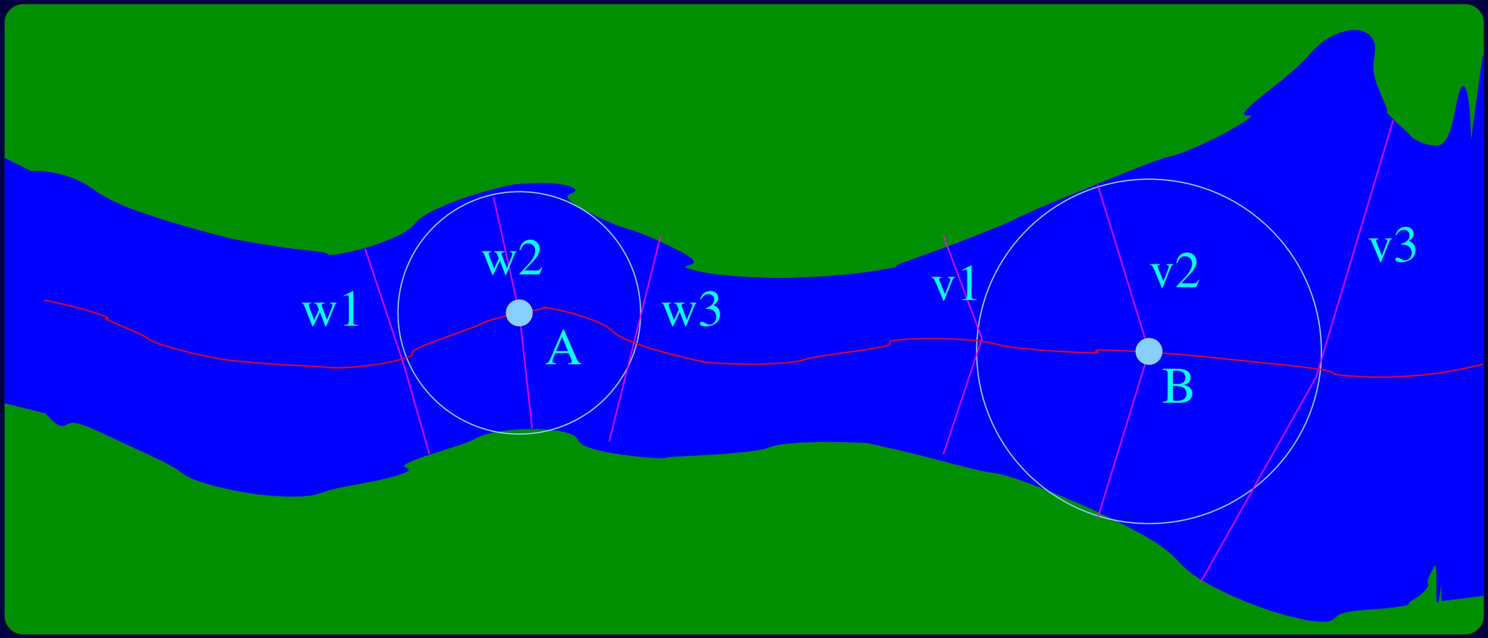


Geometrical Segmentation



A Scale Invariant Measure of Width Variation

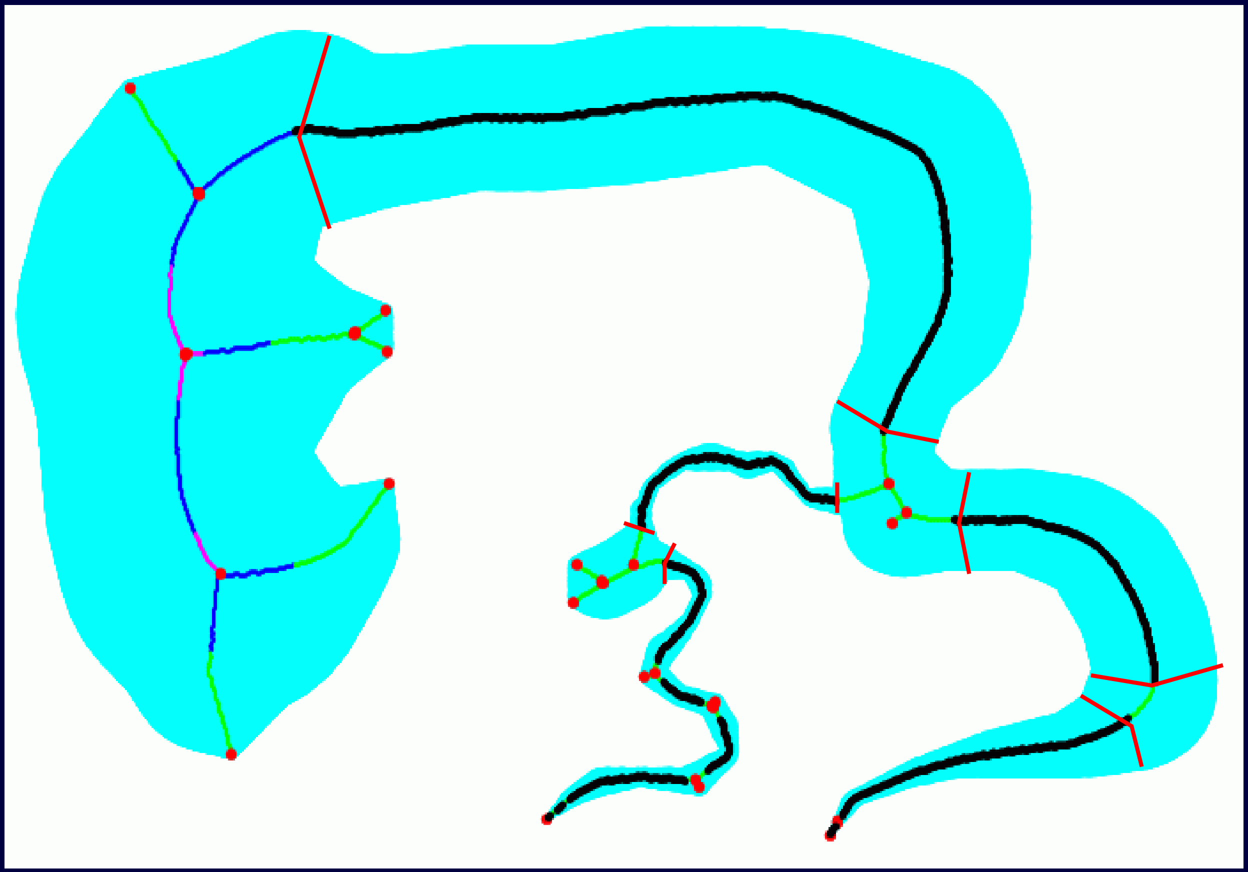


Measure percentage width variation at a point over a length of medial axis equal to (or proportional) to the width at that point.

Linear *stretches* are medial axis segments over which width variation percentage is below a given *threshold*.

Segmentation

The following segmentation is based on a single threshold parameter characterising linearity:



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