Ullman's Visual Routines and Tekkotsu Sketches

15-494 Cognitive Robotics
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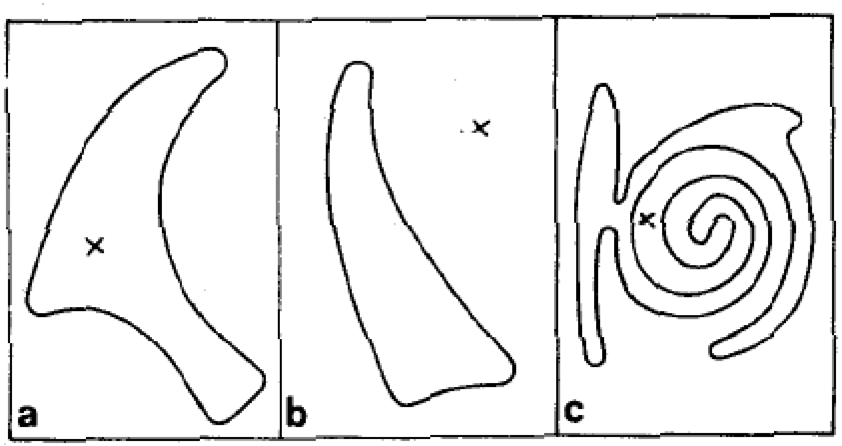
Parsing the Visual World

- How does intermediate level vision work?
  - How do we parse a scene?
- Is the x inside or outside the closed curve?

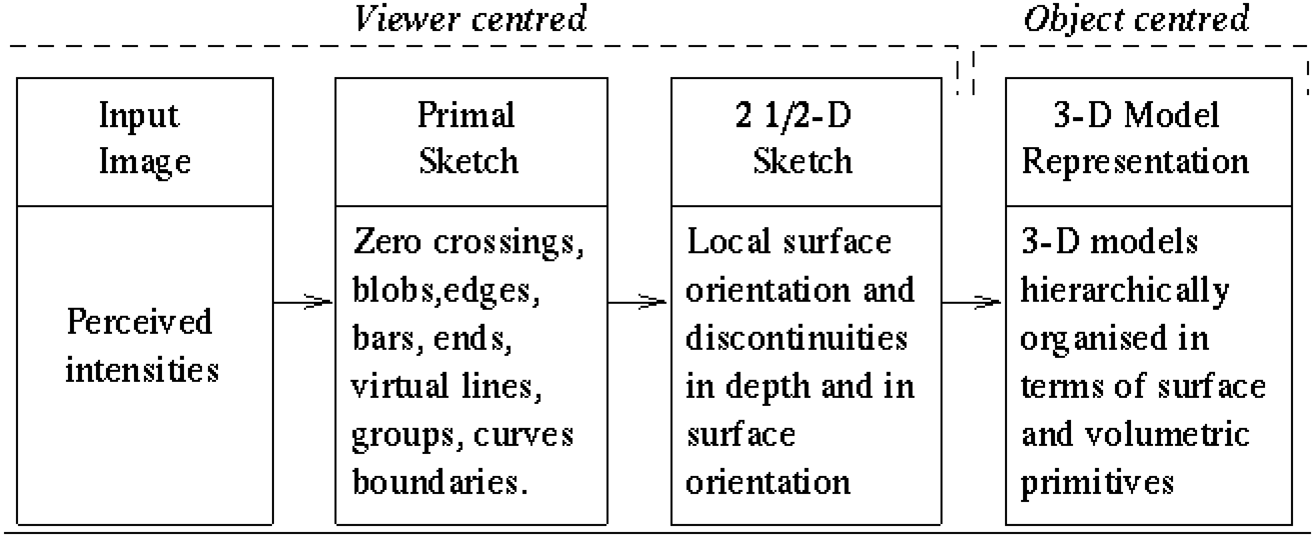


Ullman: Visual Routines

- Fixed set of composable operators.
- Wired into our brains.
- Operate on “base representations”, produce “incremental representations”.
- Can also operate on incremental representations.

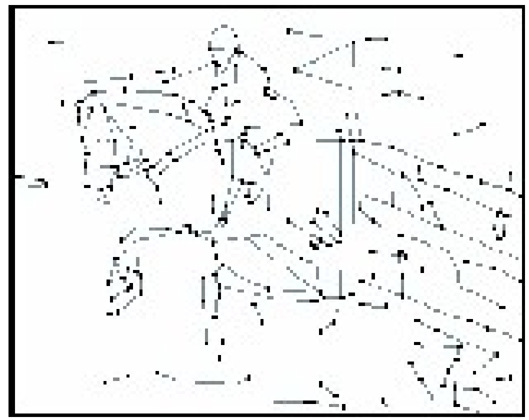
Base Representations

- Derived automatically; no decisions to make.
- Derivation is fully parallel.
  - Multiple parallel streams in the visual hierarchy.
- Describe local image properties such as color, orientation, texture, depth, motion.
- Marr's "primal sketch" and "2 ½-D Sketch"



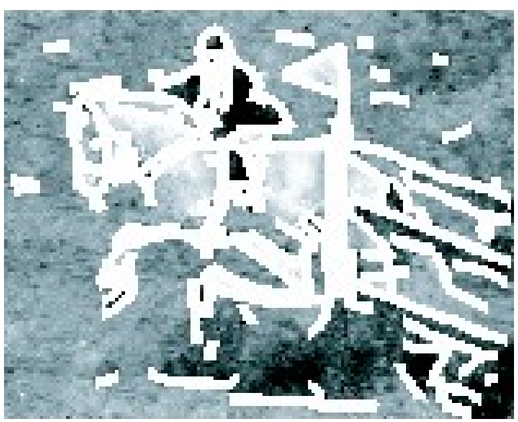
Primal Sketch

(a) input image

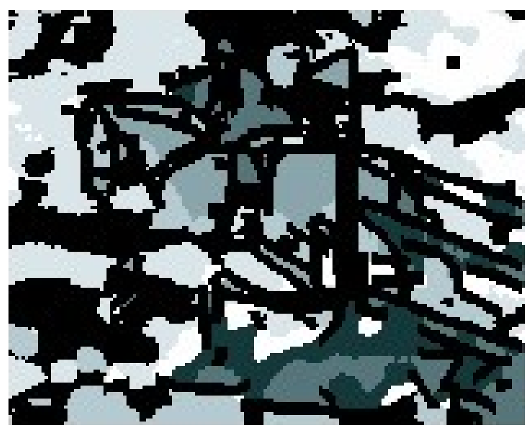


(b) sketch graph — configuration

(c) pixels covered by primitives



(d) remaining texture pixels



(e) texture pixels clustered

(f) reconstructed image

Incremental Representations

- Constructed by visual routines.
- Describe relationships between objects in the scene.
- Construction may be inherently sequential:
  - tracing and scanning take time
  - the output of one visual routine may be input to another
  - pipelining may speed things up
- Can't compute everything; too many combinations.
- The choice of which operations to apply will depend on the task being performed.
- What are these operations? Ullman gives 5 examples.

(1) Shift of Processing Focus

- Attentional operation
- Determines where in the image the next operation will be applied, e.g.:
  - A particular point
  - A particular contour
- There is extensive psychological and neurophysiological data on selective attention.

(2) Indexing

- "Odd man out" phenomenon
  - Easy to find the one element that differs from all the rest
  - But only if it differs in a basic property
- Indexable properties include:
  - Color, texture
  - Shape, size, orientation
  - Motion
- Indexing may provide the target for a shift of processing focus.
  - Example task: report the orientation of the <u>red</u> bar in a field of mostly green bars.

Triesman's Visual Search Expt.

Find the green letter:

X X X X X X X X

X X X X X X X X

X X X X X X X X

X X X X X X X X

X X X X X X X X

Triesman's Visual Search Expt.

Find the O:

X X X X X X X X

X X X X X X X X

X X X X O X X X

X X X X X X X X

X X X X X X X X

Triesman's Visual Search Expt.

Find the green O:

X X X O X X O X

X O X X X X X X

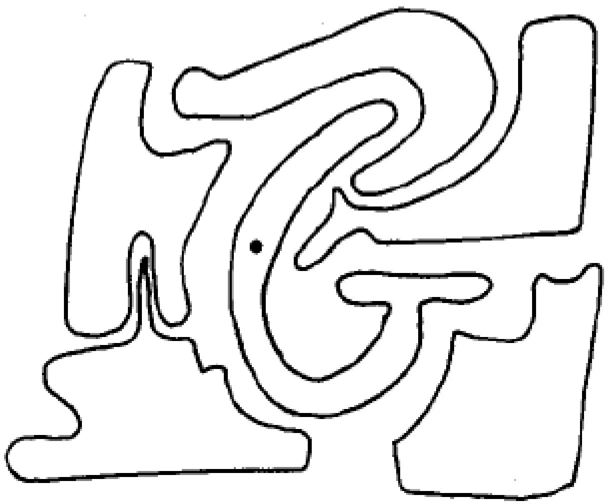
X X X X O X X X

O X X X X X X O

X X O X X X X X

(3) Bounded Activation (Coloring)

- Mark a starting point and spread activation outward.
- Spread is blocked by “boundaries”.
- Can use this to determine inside/outside relations.
- What is the subfigure containing the dot?

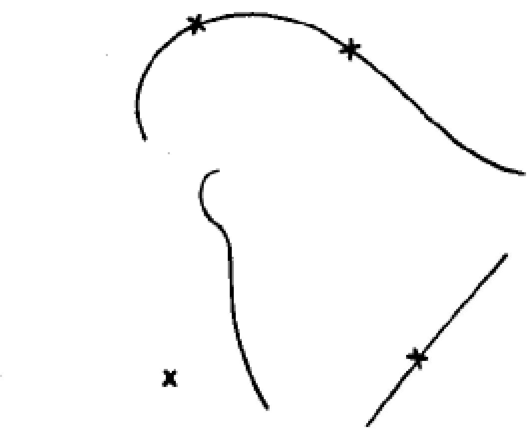


Bounded Activation in Tekkotsu

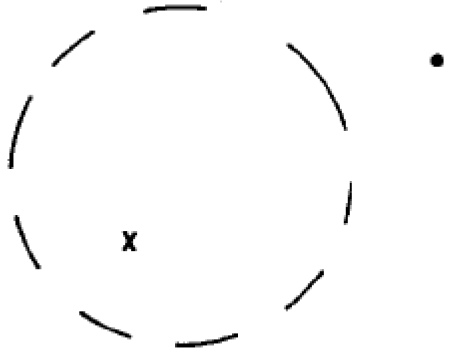
- Using a Sketch<bool> as a boundary:
  - visops::seedfill(index_t point, Sketch<bool> &boundary)
  - visops::fillInterior(Sketch<bool> &boundary)
  - visops::fillExterior(Sketch<bool> &boundary)
- Using a line shape as a boundary:
  - leftHalfPlane(Shape<LineData> &line)
    also rightHalfPlane, topHalfPlane, bottomHalfPlane
- Using a polygon shape as a boundary:
  - isInside(Point p)

(4) Boundary Tracing

- Trace along the contour until some condition is met.
- Example: detect open vs. closed curves.
  - Open curves have termination p

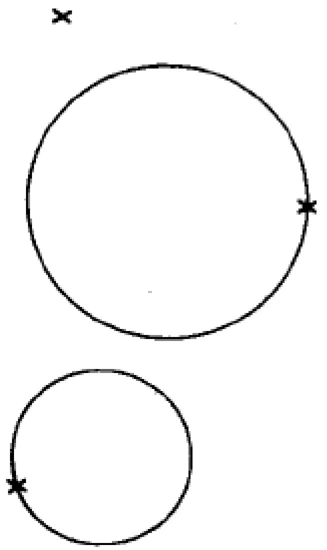


- Does any curve contain two x's?
- Contours may not be trivial to recognize: could be broken, or implicit.



(5) Marking

- Place a marker at a location.
- Useful for remembering locations or structures that have already been examined. Are any two x's on a common curve?



- Can also be used to designate a point of interest for later processing.

Points in Tekkotsu

- fmat::Column<3> or fmat::Column<4>
  - Used internally for arithmetic calculations
- Point
  - Contains an fmat::Column<3>
  - Also contains a ReferenceFrameType_t
  - Used by shapes for point arithmetic
- EndPoint
  - Includes **valid** and **active** booleans
- Shape<PointData>

Marking in Tekkotsu

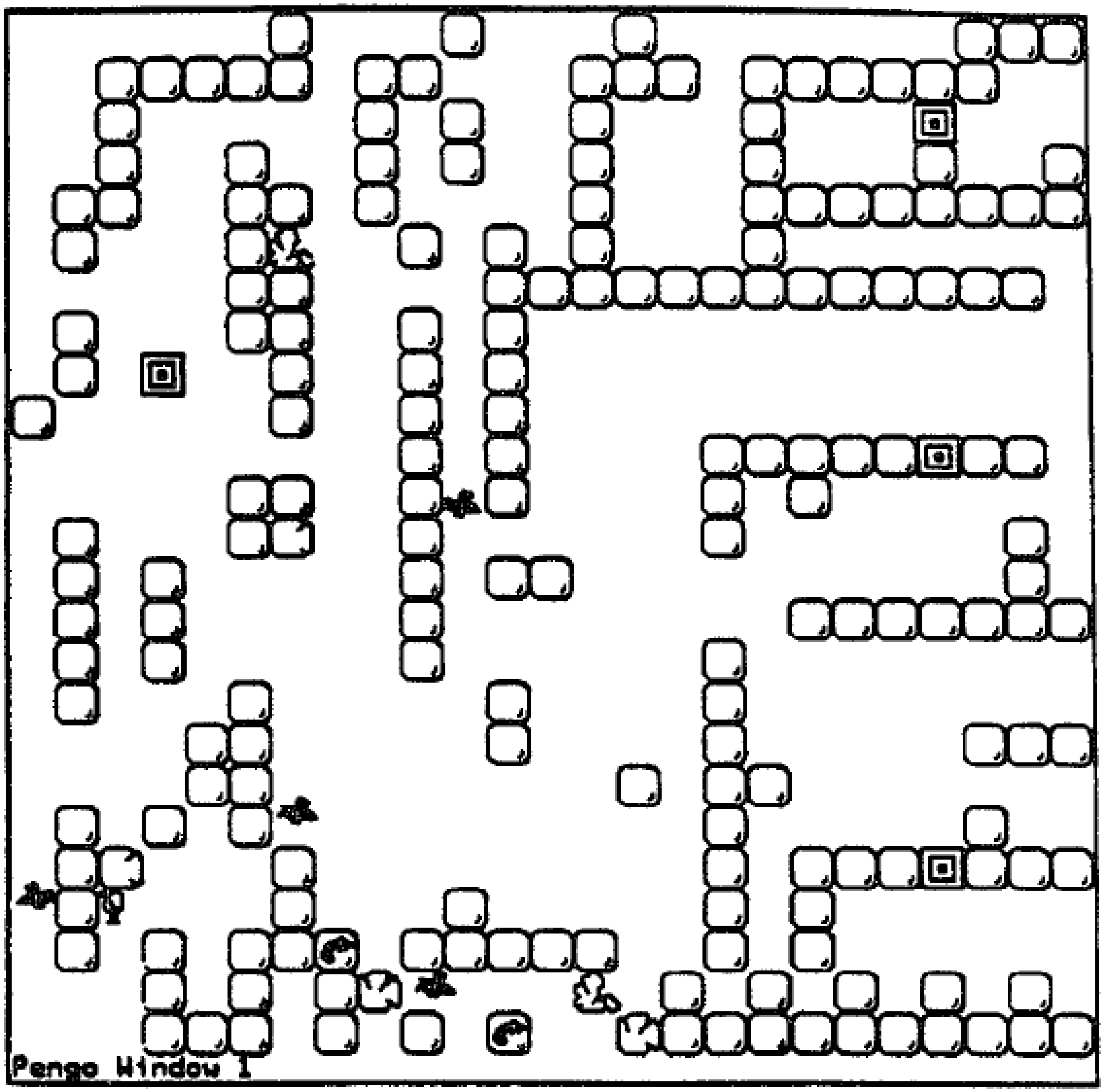
- Marking a point:
  - Can use a Sketch<bool> with a single pixel set.
  - Can use a Shape<PointData>
- Marking an object:
  - Can use a Sketch<bool> to show rendering of the object.
  - Can add a shape to a SHAPEVEC

(6) Ray Tracing

- Not included in Ullman's list.
- But mentioned in an earlier section of the paper.
- Start at a point and trace outward in a straight line until you reach something of interest.
- Which way should the line go?
  - Trace in a particular direction, e.g., “upward”?
  - Trace toward an object of interest?
- Used by Agre & Chapman in Pengi.

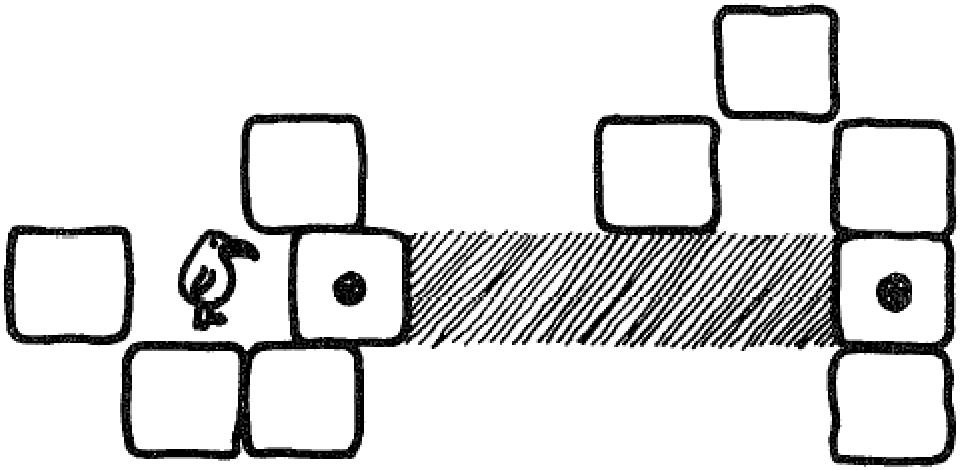
Agre & Chapman's Pengi

An AI program that plays the Pengo video game:



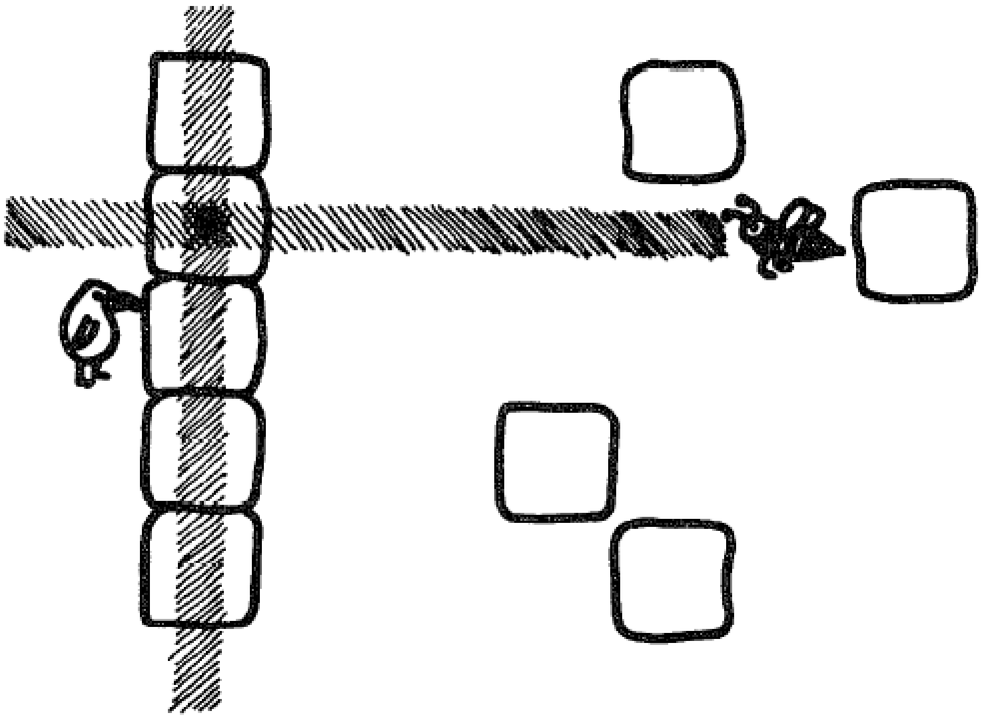
See videos of the original Pengo arcade game on YouTube.

Visual Routines in Pengi



Finding *the-block-that-the-block-I-just-kicked-will-collide-with* using ray tracing and dropping a marker.

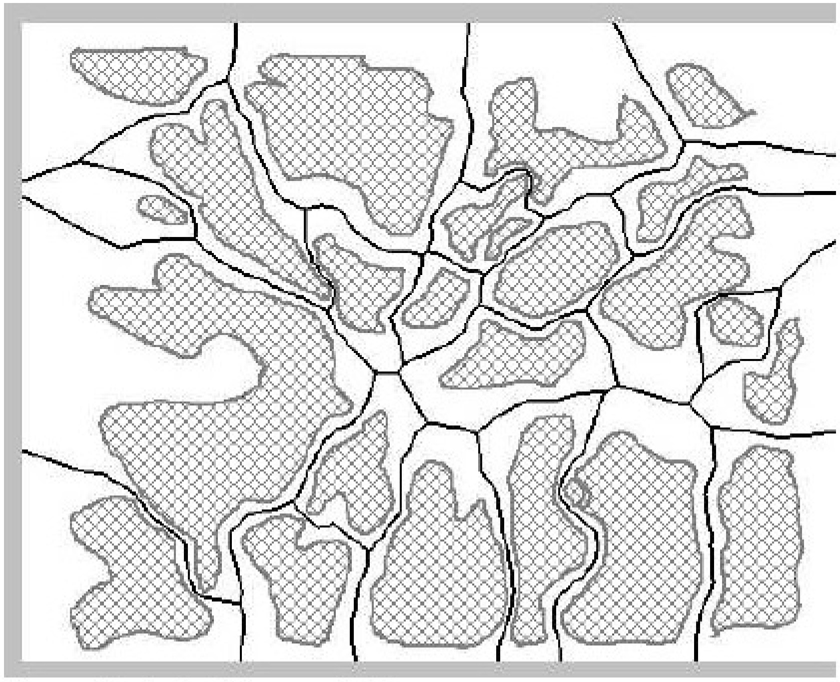
Visual Routines in Pengi



Finding *the-block-to-kick-at-the-bee* when lurking behind a wall.

Visual Routines in Game AI

- Forbus et al.: visual routines could be used for qualitative spatial reasoning, such as path finding in AI strategy games.
- Example: Voronoi diagram of open space on a map can be used for route finding.



Snapshot 3: Voronoi diagram

VDdiag(a) =
  edge(read(labelcc(a), link(a)))

Application to Tekkotsu?

- Can create sketch spaces for local or world maps.
- setTmat(scale,tx,ty) controls the mapping of shape space coordinates to sketch space pixels.
- getRendering() converts shapes to sketches.
- Marking and coloring can be implemented using sketches.
- Might use this to implement Pengi-like logic for robotics applications.
- But we need more primitives…

Do Tekkotsu's Representations Fit Ullman's Theory?

- What are the base representations?
  - color segmented image: sketchFromSeg()
  - intensity image: sketchFromRawY()
  - depth image: sketchFromDepth()
  - extracted regions
- What are the incremental representations?
  - Sketches
  - Shapes
- What's missing?
  - Attentional focus; boundary completion; lots more.

What Do Human Limitations Tell Us About Cognition?

- Subjects can't do parallel visual search based on the intersection of two properties (Triesman).
- This tells us something about the architecture of the visual system, and the capacity limitations of the Visual Routines Processor.
  - Base can't do intersection.
  - VRP can't process whole image at once.
  - There must be a *limited channel* between base and VRP.
- But in Tekkotsu, we can easily compute intersections of properties.
  - Is that a problem?

Science vs. Engineering

- Science: figure out how nature works.
  - Limitations of a model are good if they suggest that the model's structure reflects reality.
  - Limitations should lead to nontrivial predictions about comparable effects in humans or animals.

- Engineering: figure out how to make useful stuff.
  - Limitations aren't desirable.
  - Making a system “more like the brain” doesn't in itself make it better.

- What is Tekkotsu trying to do?
  - Find good ways to program robots, drawing *inspiration* from ideas in cognitive science.