Building Recognizers for Digital Ink and Gestures

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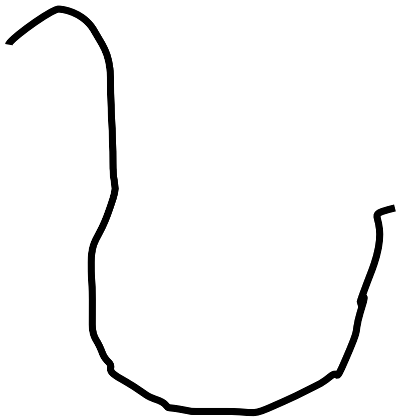
Digital Ink

- Natural medium for pen-based computing
  - Pen inputs strokes
  - Strokes recorded as lists of X,Y coordinates
  - E.g., in Java:
    - Point[] aStroke;



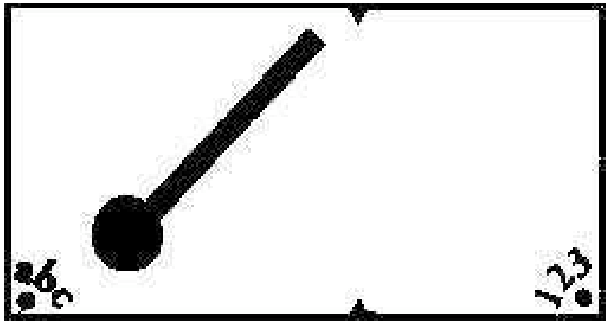
- Can be used as *data* -- handwritten content
- ... or as *commands* -- gestures to be processed

Distinguishing Content from Commands

- Depends on the set of input devices, but ....
  - generally **modal**
  - Meaning that you're either in content mode or you're in command mode
- Often a button or other model selector to indicate command mode
  - Example: Wacom tablet pen has a mode button on the barrel
  - Temporary switch--only changes mode while held down, rather than a toggle.

Other Options

- Use a special character that disambiguates from content input and command input
  - E.g., graffiti on PalmOS
  - “Command stroke” says that what comes after is meant to be interpreted as a command.



- Can also have special “alphabet” of symbols that are unique to commands
- Can also use another interactor (e.g., the keyboard)
  - but requires that you put down the pen to enter commands

Still More Options

- "Contextually aware" commands
- Interpretation of whether something is a command or not depends on where it is drawn
  - E.g., Igarashi's Pegasus drawing beautification program
    - a scribble in free space is content
    - a scribble that multi-crosses another line is interpreted as an erase gesture

Why Use Ink as Commands?

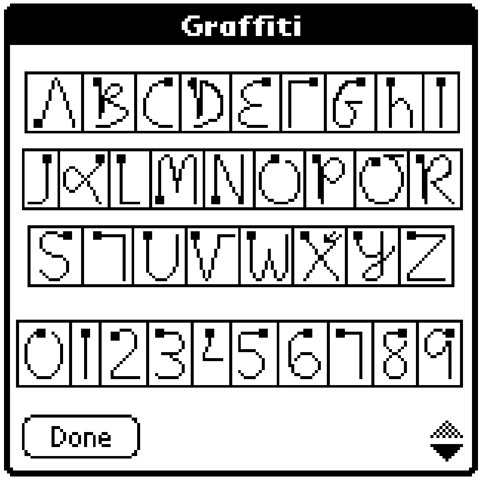
- Avoids having to use another interactor as the “command interactor”
  - Example: don’t want to have to put down the pen and pick up the keyboard
- What’s the challenge this with, though?
  - The command gestures *have* to be interpreted by the system
  - Needs to be reliable, or undoable/correctable
  - In contrast to content:
    - For some applications, uninterpreted content ink may be just fine

Content Recognizers

- Feature-based recognizers:
- Canonical example: Dean Rubine, *The Automatic Recognition of Gestures*, Ph.D. dissertation, CMU 1990.
  - "Feature based" recognizer, computes range of metrics such as length, distance between first and last points, cosine of initial angle, etc
  - Compute a *feature vector* that describes the stroke
  - Compare to feature vector derived from training data to determine match (multidimensional distance function)
  - To work well, requires that values of each feature should be normally distributed within a gesture, and between gestures the values of each feature should vary greatly

Content Recognizers [2]

- "Unistrokes" (a la PalmOS Graffiti)
- Use a custom alphabet with high-disambiguation potential
- Decompose entered strokes into constituent strokes and compare against template
  - E.g., unistrokes uses 5 different strokes written in four different orientations (0, 45, 90, and 135 degrees)
- Little customizability, but good recognition results and high data entry speed
- Canonical reference:
  - D. Goldberg and C. Richardson, *Touch-Typing with a Stylus*. Proceedings of CHI 1993.



Content Recognizers [3]

- Waaaaay more complex types of recognizers that are out of the scope of this class
  - E.g., neural net-based, etc.

This Lecture

- Focus on recognition techniques suitable for **command gestures**
- While we can build these using the same techniques used for **content ink**, we can also get away with some significantly easier methods
  - Read: “hacks”
- Building general-purpose recognizers suitable for large alphabets (such as arbitrary text) is outside the scope of this class
- We’ll look at two simple recognizers:
  - 9-square
  - Siger

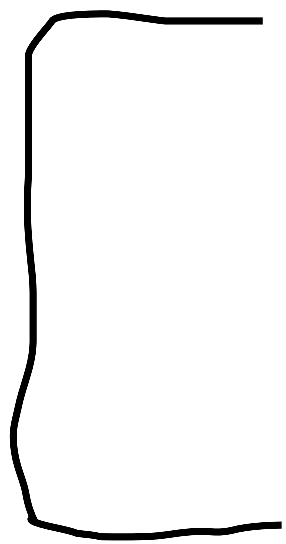
9-square

- Useful for recognizing "Tivoli-like" commands
- Developed at Xerox PARC for use on the Liveboard system
  - Liveboard [1992]: 4 foot X 3 foot display wall with pen input
- Used in "real life" meetings over a period of several years, supported digital ink and natural ink gestures

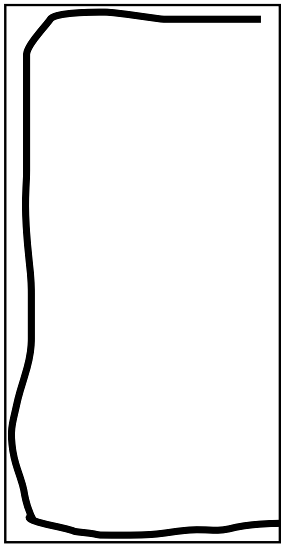
“9 Square” recognizer

- Basic version of algorithm:
  1. Take any stroke
  2. Compute its bounding box
  3. Divide the bounding box into a 9-square tic-tac-toe grid
  4. Mark which squares the stroke passes through
  5. Compare this with a template

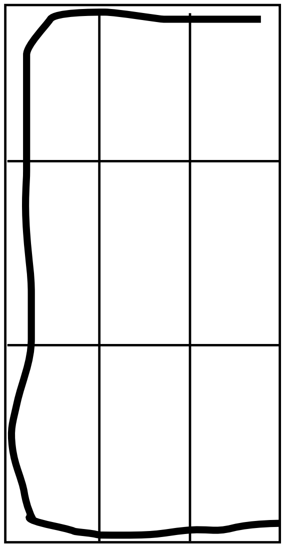
1. Original Stroke



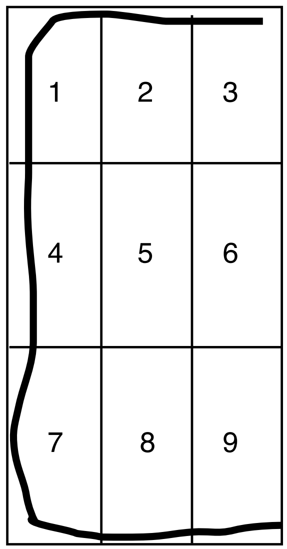
2. Compute Bounding Box



3. Divide Bounding Box into 9 Squares (3x3 grid)

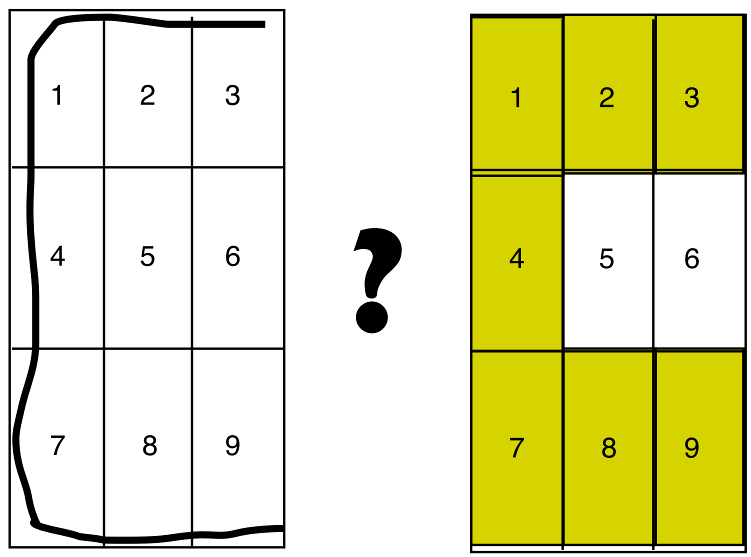


4. Mark Squares Through Which the Stroke Passes



representation: [X, X, X,
X, 0, 0,
X, X, X]

5. Compare with Template



stroke: [X, X, X,
X, 0, 0,
X, X, X]

=

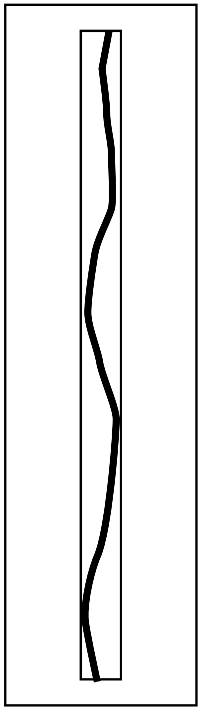
template: [X, X, X,
X, 0, 0,
X, X, X]

Implementing 9-square

- Create set of templates that represent the intersection squares for the gestures you want to recognize
- Bound the gesture, 9-square it, and create a vector of intersection squares
- Compare the vector with each template vector to see if a match occurs

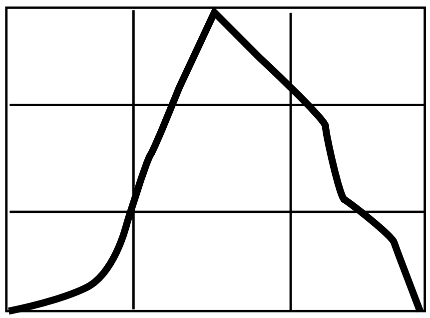
Gotchas [1]

- What about long, narrow gestures (like a vertical line?)
- Unpredictable slicing
  - A perfectly straight vertical line has a width of 1, impossible to subdivide
  - More likely, a narrow but slightly uneven line will cross into and out of the left and right columns
- Solution: pad the bounding box before subdividing
  - Can just pad by a fixed amount, or
  - Pad separately in each dimension
    - Long vertical shapes may need more padding in the horizontal dimension
    - Long horizontal shapes may need more padding in the vertical dimension
    - Compute a pad factor for each dimension based on the other



Gotchas [2]

- Hard to do some useful shapes, e.g., vertical caret
- Is the correct template
  [0, X, 0,
0, X, 0,
X, 0, X] or.... [0, X, 0,
X, 0, X,
X, 0, X]



- ... or other similar templates?
- Inherent ambiguity in matching the symbol as it is likely to be drawn to the 9-square template
- Any good solutions?

Gotchas [2]

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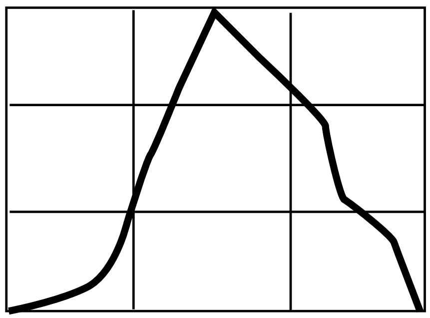
- Is the correct template

  [0, X, 0,
   0, X, 0,
   X, 0, X]

  or....

  [0, X, 0,
   X, X, X,
   X, 0, X]



- ... or other, similar templates?
- Inherent ambiguity in matching the symbol as it is likely to be drawn to the 9-square template
- Any good solutions?
- **Represent that ambiguity**
- Introduce a "don't care" symbol into the template

Don’t Cares

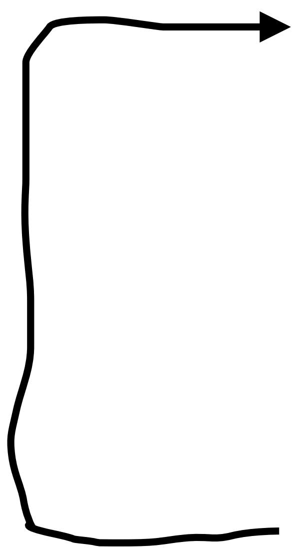
- Use 0 to represent no intersection
- Use X to represent intersection
- Use * to represent don’t cares

- Example: [0, X, 0,
*, *, *,
X, 0, X] or... [0, X, 0,
*, X, *,
X, 0, X]

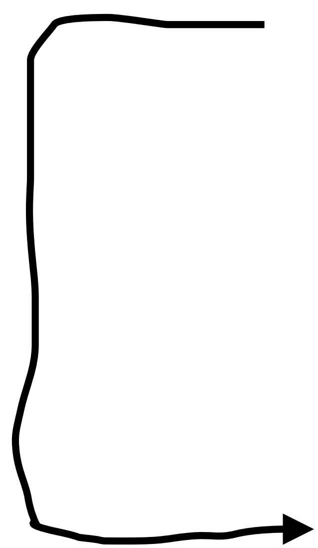
- Now need custom matching process (simple equivalence testing is not “smart enough”)
- if stroke[i] == template[i] || template[i] == “*”

An Enhancement

- What if we want direction to matter?
- Example:

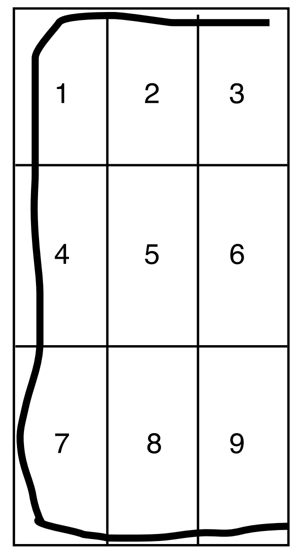


Versus

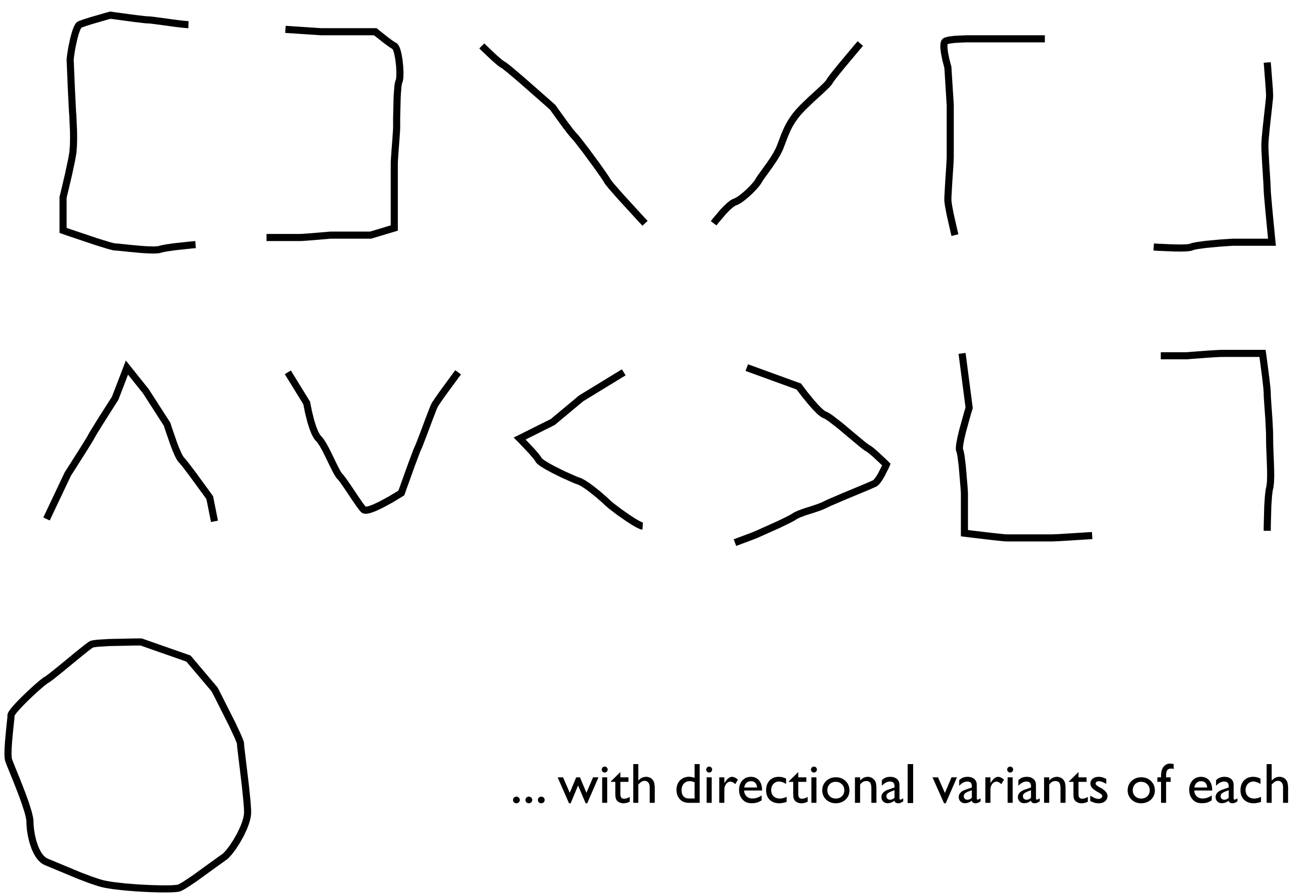


Directional Nine-Squares

- Use an alternative stroke/template representation that preserves ordering across the subsquares
- Example:
  - top-to-bottom: {3, 2, 1, 4, 7, 8, 9}
  - bottom-to-top: {9, 8, 7, 4, 1, 2, 3}
- Can be extended to don't cares also
- (Treat don't cares as wild cards in the matching process)



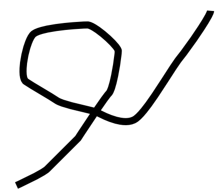
Sample 9-square Gestures



... with directional variants of each

Another Simple Recognizer

- 9-square is great at recognizing a small set of regular gestures
- ... but other potentially useful gestures are more difficult
  - Example: "pigtail" gesture common in proofreaders' marks



- Do we need to go to a more complicated "real" recognizer in order to process these?
- **No!**

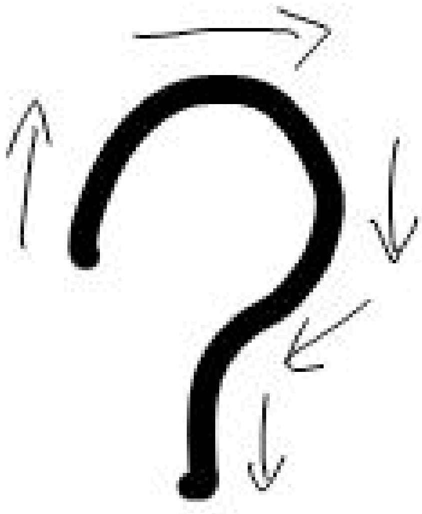
The SiGeR Recognizer

- SiGeR: Simple Gesture Recognizer
- Developed by Microsoft Research as a way for users to create custom gestures for Tablet PCs
- Resources:
  - http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dntablet/html/tbconCuGesRec.asp
  - http://sourceforge.net/projects/siger/ (C# implementation)
- Big idea: turn gesture recognition problem into a regular expression pattern matching problem

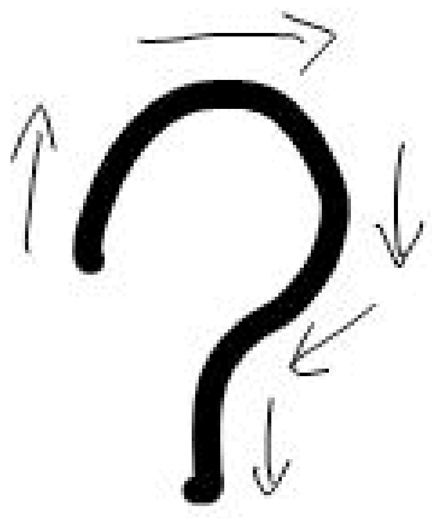
Basic Algorithm

1. Processes successive points in the stroke
2. Compute a direction for each stroke relative to the previous one, and output a direction vector of the directions
3. Compare the direction vector to a pattern expression; can even use standard regular expression matching

1. Process Successive Points in the Stroke

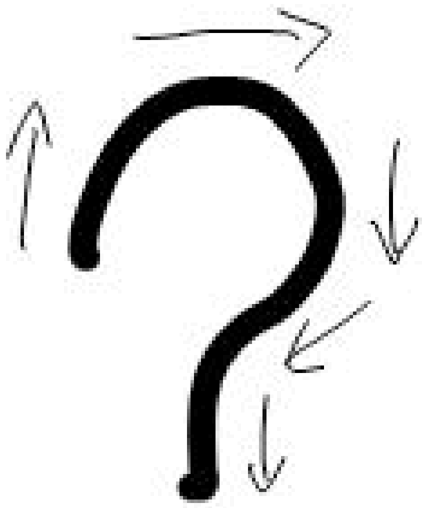


2. Compute a direction vector based on each point



U, U, U, RU, RU, RU, RU, L, L, L,
LD, D, D, RD, RD, RD, D, D, D

3. Compare the string to a directionality template



U, U, U, RU, RU, RU, RU, R, R, R,
RD, D, D, LD, LD, LD, D, D, D

Template = [UPS, RIGHTS, DOWNS, LEFTS, DOWNS]
(defines basic shape of the stroke)

Defining the Template

- Concerned about matching 8 possible pen directions
  - RIGHT, UP, LEFT, DOWN, RIGHT-UP, RIGHT-DOWN, LEFT-UP, LEFT-DOWN
- Template consists of these symbols
- ... plus "grouping" symbols that match more general directions
  - UPS matches all things that go up: UP, RIGHT-UP, LEFT-UP
  - LEFTS matches all things that go left: LEFT, LEFT-UP, LEFT-DOWN
- The template is then matched against the direction vector by seeing if the template patterns occur

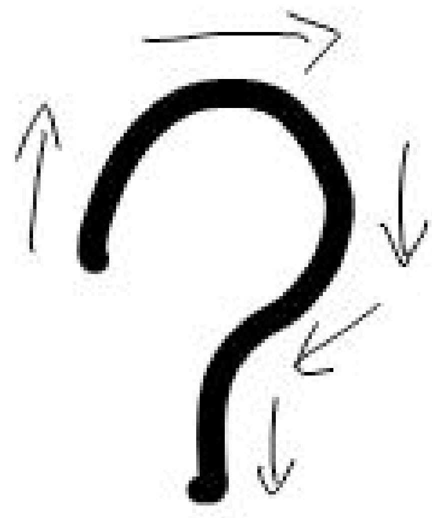
How Robust is This?

- Here's a gesture that shouldn't match but may, depending on implementation
- Why?
  - A question mark appears in the middle of the stroke

- Therefore:
  - Important to match the **whole** stroke, not just **part** of it!
  - Think of the pattern as including ^ and $ (regular expression markers for beginning of line and end of line) at the first and end

How Robust is This?

- But requiring the **entire** stroke to match the pattern introduces a new problem
- Can you tell what it is?



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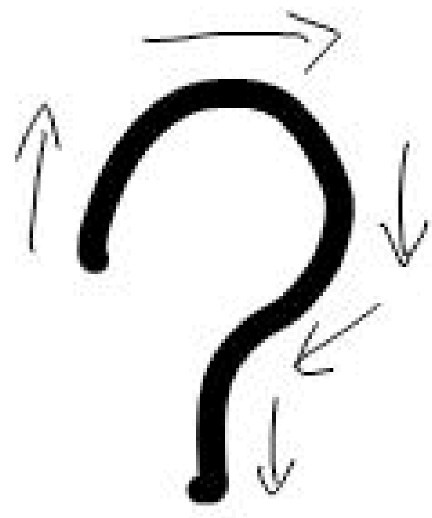

- Look closely at the question mark
  - At the bottom, the stroke jags off to the left
  - Common for the pen to make little tick marks like this when it comes into contact with the tablet, or leaves it

Solution

- Simply trim the beginning and end points of the vector!
- More generally:
  - Ignore small outlier points if the overall shape otherwise conforms to the shape pattern specified in the template.

Implementing SiGeR (one method)

- Specify some helper constants:

```
int UP = (1<<0);
int DOWN = (1<<1);
// ... define other constants, as well as unique tokens that represent
// direction classes
int RIGHT_UP = (RIGHT | UP);
int UPS = (UP | RIGHT_UP | LEFT_UP);
```

- Specify templates in code, using human-readable constants:

```
int QUESTION_MARK = { UPS, RIGHTS, DOWNS, LEFTS, DOWNS };
```

Implementing SiGeR (continued)

- Create a function buildPatternString() that takes the template and emits a regexp pattern that will be used to match it

```
buf.append("^");               // match the start of input
buf.append(".{0,2}+");         // consume any character 0-2 times (this gets rid of the noise at the beginning)
for (int i=0 ; i<pattern.length ; i++) {
    switch (pattern[i]) {      // emit a unique letter code for each of the 8 directions
        case RIGHT: buf.append("R+"); break;
        case UP: buf.append("U+"); break;
        case RIGHT_UP: buf.append("W+"); break;
        case LEFT_UP: buf.append("X+"); break;
        // ...
        case UPS: buf.append("[UWX]+"); break;    // combination directions combine letters
    }
}
buf.append(".{0,2}+);
buf.append("$");
```

Implementing SiGeR (Cont'd)

- Write a function buildDirectionVector() that takes an input stroke and returns a direction vector
  - Compare each point to the point previous to it
  - Emit a symbol to represent whether the movement is UP, RIGHT, etc.
  - (using all of the 8 ordinal directions)
- Use the Java regular expression library to match strokes to patterns!

```
import java.util.regex.*;
if (questionMarkPattern.matcher(strokeString).find()) {
    // it's a question mark!
}
```

More on SiGeR

- SiGeR actually does much more than this; we're just implementing the most basic parts of it here.
- Example: collects statistical information about strokes that can be used to disambiguate them
  - Percentage of the stroke moving right, distance between the start and end points, etc.
  - Can help disambiguate a ring from a square
- Also computes various other features
  - Are shapes open or shut, pen velocity, etc.
  - Can tweak patterns by requiring certain features