Online Handwriting Recognition Technology - State of the Art

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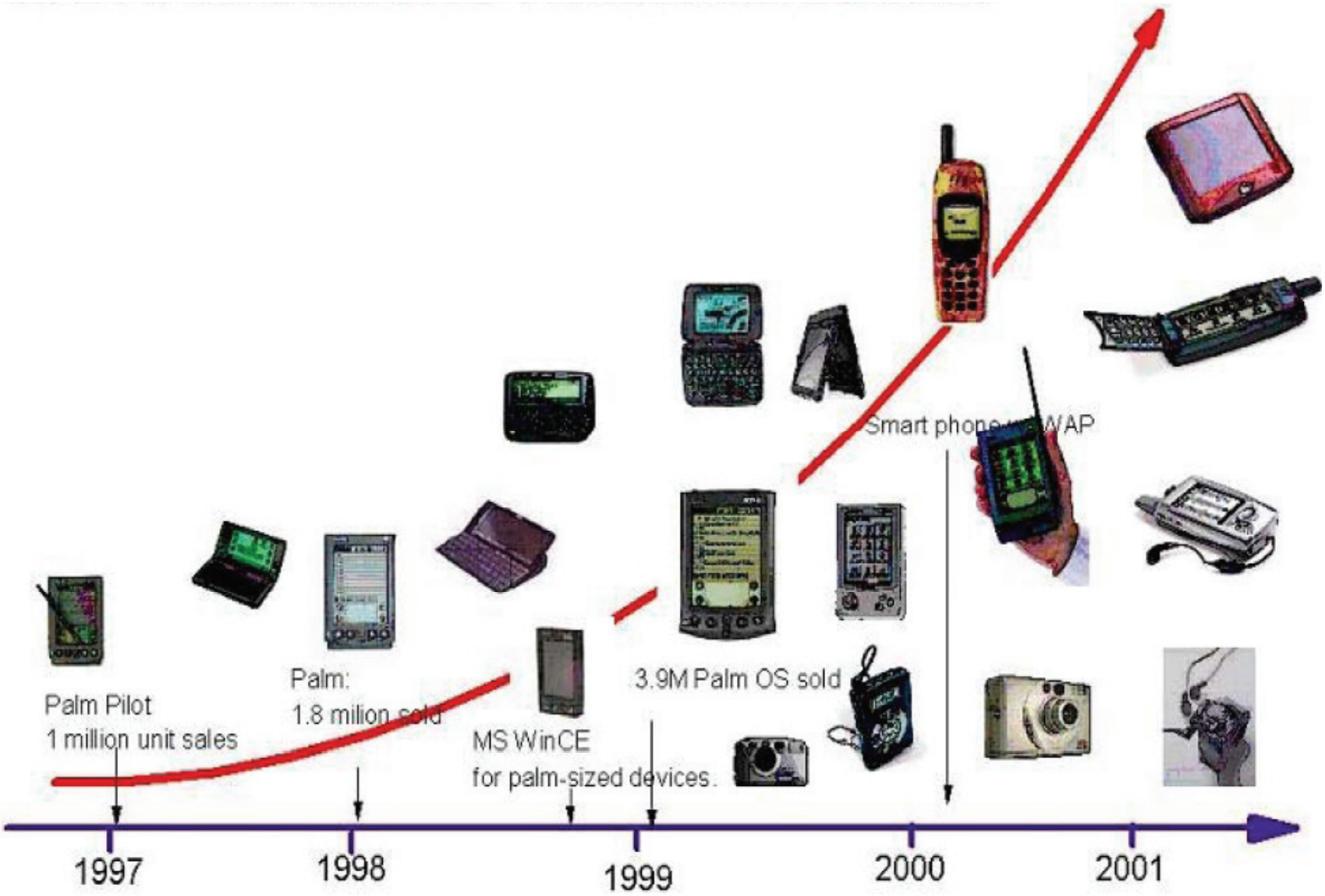
My Background

- Designed and implemented the IBM embedded large vocabulary, multi-lingual (English, simplified and traditional Chinese, Japanese) online handwriting recognizer for mobile devices.
- Team lead - R&D of the IBM full page online handwriting recognizer for Asian languages (simplified Chinese, traditional Chinese and Japanese) on desktop/laptop computers (shipped in ThinkScribe, a.k.a CrossPad, and ThinkPad TransNote) at IBM China Research Lab.

The Proliferation of Handheld Devices



Agenda

- A Brief History
- Handwriting Recognition – Categorization and Related Applications
- Review of Classic On-line Handwriting Recognition Algorithms
- Embedded Handwriting Recognition Technology
- Pen Interfaces for Recognizers
- Conclusions
- Demo , Q&A

A Brief History

- 1914 Hyman Eli Goldberg, U.S. Patent 1,117,184, On-line recognition of hand-written numerals to control a machine in real-time.
- 1938 George Hansel, U.S. Patent 2,143,875, machine recognition of handwriting.
- 1957 T. L. Dimond's stylator - the first on-line handwriting recognizer prototype
- Newton, Pen Computer, Palm, Crosspad, Thinkpad TransNote and TabletPC

Handwriting Recognition - Categorization and Applications

- Printed Character Recognition (OCR)
  - Relatively mature these days, key challenges – layout analysis, fonts recovery, robust recognition for low quality, low resolution input
  - Major applications: digital library, document management, digitize legacy paper publications, portable dictionary
- Handwritten Character Recognition
  - Online HWR (with temporal info, i.e. stroke trace info)
    - Character, Word, Sentence Level
    - Text entry, Gesture Command & Control, Annotation & Retrieval
  - Offline HWR (using raster image as input, no temporal info)
    - A rich test bed for pattern recognition research
    - Major Usage - Postal automation, census automation, automatic form processing

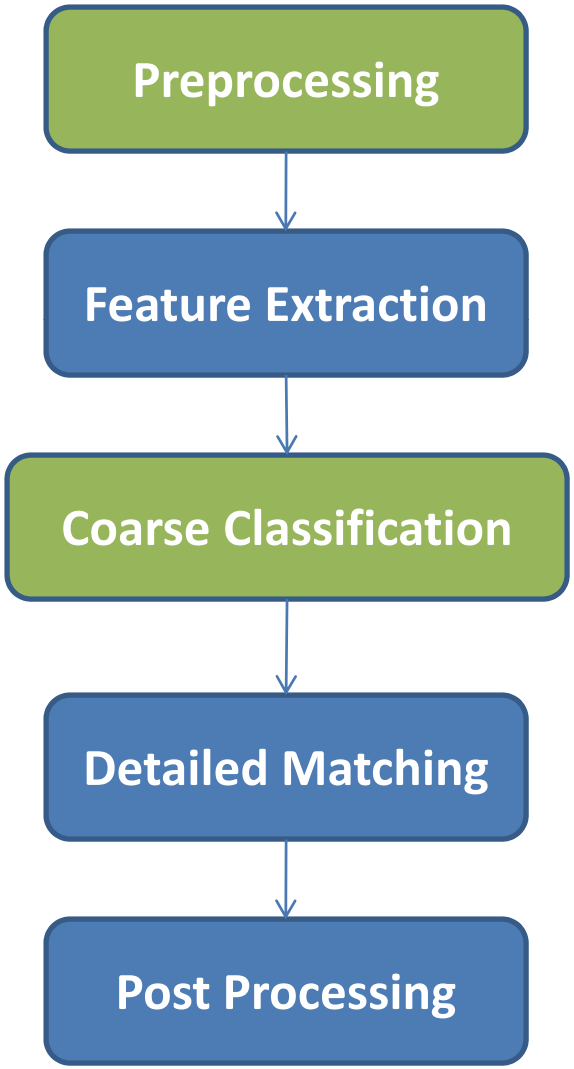
Beyond Individual Characters – Word and Sentence Level Recognizer

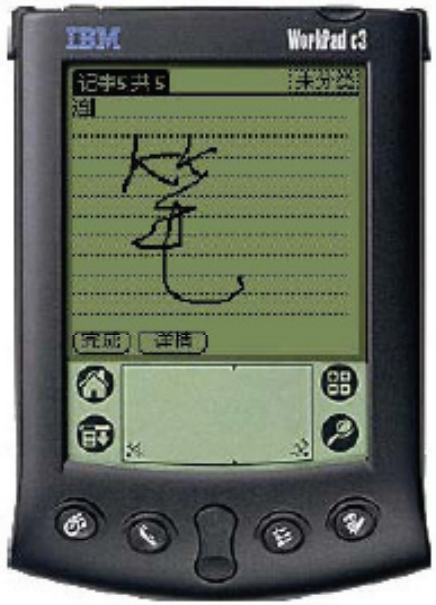
- Build on top of the character recognizer
- General strategy:
  - Over segmentation
  - Calling a character/component recognizer, getting a list of candidates with scores
  - Applying geometry spatial information (size, component gap) and language information (dictionary, language model etc) to each sub path
  - Using hypothesis search (Dynamic Programming, A*, Beam Search etc) to determine the best possible path

Challenges in Online Handwriting Recognition

- Character set/Dictionary Size
  - 6763 Characters in GB2312 (Simplified Chinese)
  - 13K Characters in BIG5 (Traditional Chinese)
  - 5k Characters in JIS (Japanese)
- Stroke number variations
  - Cursive Writing Styles/Broken strokes/duplicate strokes/omitted components
- Stroke order variations
- Limited memory and Computing Power on Small Devices

A Generic Recognition Workflow





Common Recognition Algorithms

- Knowledge/Heuristic Based
  - Decision Tree
  - Hand coded (Fuzzy logic :-))
- Global Feature Vector Matching
  - Parameter or Non-parameter classifier(KNN)
  - Neural Network (MLP, LVQ, PNN..)
  - Support Vector Machine (SVM)
- Structure Based Methods
  - Dynamic Programming/DTW
  - Graph Matching (e.g. DAG matching)
  - Hidden Markov Model
  - Time Delay Neural Network (TDNN)
  - Heuristics based stroke correspondence

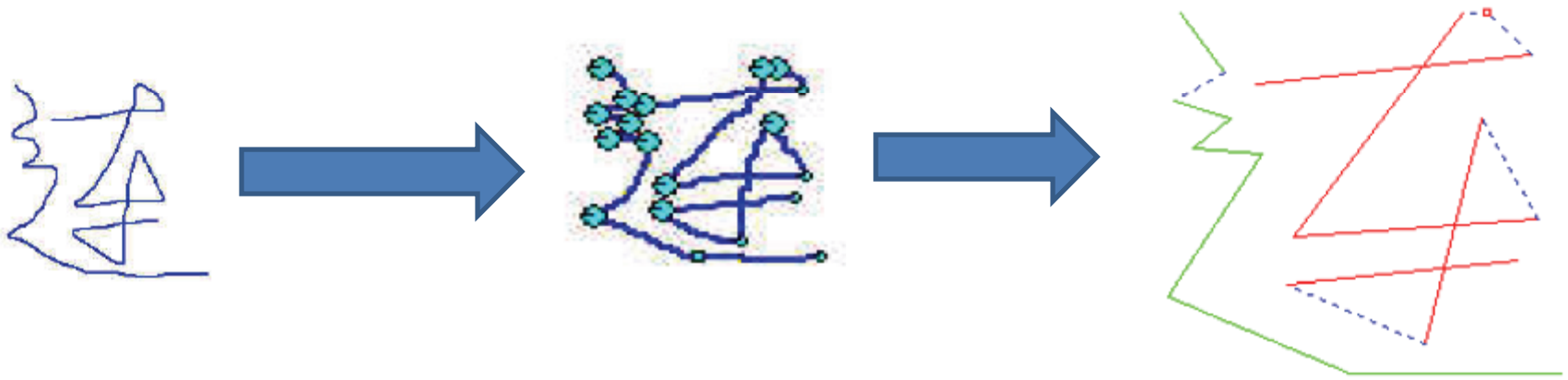
Global Feature Vector Matching

- Classifier itself is usually not the most influential factor on accuracy !(less than 10%)
  - However, different classifiers do have different pros and cons in speed, charset switching, largest supported class number, training difficulty.
- Feature extraction/selection usually determines the upper bound of performance
- Common pitfalls
  - Extract multiple feature types and use them directly
  - Extract too many dimensions of feature

Structure Based Methods

- Construct sub-components of handwriting, then use some algorithms to solve the component correspondence problem between the input and the prototypes
- Commonly used sub-components
  - Loop points, Crisp points, Cross points, Curvature points (usually for Western languages)
  - Stroke, Stroke segment (linear approximation of strokes)
  - Start, end points, equal distance/equal number sampling points
  - Radicals (usually for Asian Languages)

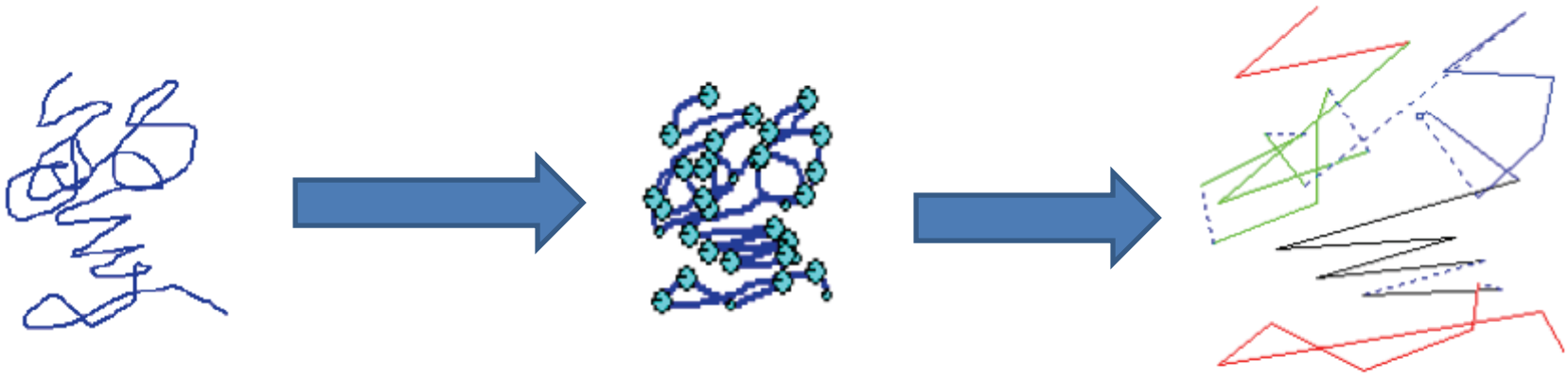
Examples of a HMM Based Recognizer



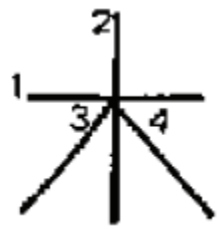
Original Input

After preprocessing, Segmentation and Feature Points Detection

Matching/Correspondence Results after Backtracing



An Example of Stroke Correspondence



Template

Input Pattern

	木	A	B	C	D
1	—	d_{1A}	d_{1B}	d_{1C}	d_{1D}
2	丨	d_{2A}	d_{2B}	d_{2C}	d_{2D}
3	丿	d_{3A}	d_{3B}	d_{3C}	d_{3D}
4	丶	d_{4A}	d_{4B}	d_{4C}	d_{4D}

$$D(x) = D_{1b}+D_{2A}+D_{3C}+D_{4D}$$

$$D = \min\{ D(x) \}$$

Commonly Used Recognizer Training Algorithms

- Competitive Learning (SOM, LVQ)
- Linear Programming (SVM)
- Back-Propagation (MLP)
- Expectation-Maximization (HMM, GMM)
- Boosting
- Clustering Algorithms
- PCA, LDA, FA and their variations
- Nonlinear function optimization methods
- Randomized Algorithms (MCMC, Simulated Annealing)
- Brute Force method

Trends in Current HWR research

- Using multiple classifiers to achieve robustness to handle input variations – Classifier Combination
  - Classifier voting, Confusion matrix, Decision classifier, Confidence value transformation
- Obtaining the parameters of a recognizer from large training data set, not from heuristics
- Using transformations to capture delicate shape variations (e.g. SAT)
- Leveraging powerful but time-consuming training algorithms
- User Adaptation Algorithm (Writer dependent recognition)

Major Player on This Arena (Desktop)

- English
  - IBM - Used in CrossPad, ThinkPad TransNote
  - Microsoft - In OfficeXP, TabletPC (licensed part of source codes from Paragraph)
  - Motorola
  - Paragraph
- Chinese/Japanese
  - IBM
  - Motorola
  - Hanwang - Licensed to Microsoft for TabletPC
  - PenPower
  - Wintone
  - FineArts

Players in this Area (Embedded/Lightweight)

- English
  - ART - ART Recognizer
  - CIT - Jot
  - IBM - Derived from the Multi-lingual version
  - Microsoft - Transcriber (Licensed version of Calligrapher) & Self developed single character recognizer
  - Motorola
  - Paragraph - Calligrapher
- Chinese/Japanese
  - FineArt – GoGo Pen
  - Hanwang - more than 70% PDA market share in mainland China
  - IBM Embedded HWR
  - Motorola Lexicus - DragonPen
  - PenPower – the most influential vendor in Taiwan

Lessoned Learned

- Collect a large enough data set (at least 200 * charset size) before the start of your research
- Trade-offs are necessary to compromise time & space
- No one-size-fits-all recognition algorithm, classifier combination is usually an effective solution
- Recognition algorithm is not simply a combinational optimization problem - must adapt your recognition model to human cognition model
- Train your recognizer, not code your recognizer!
- Beware of the curse of dimension (CoD)

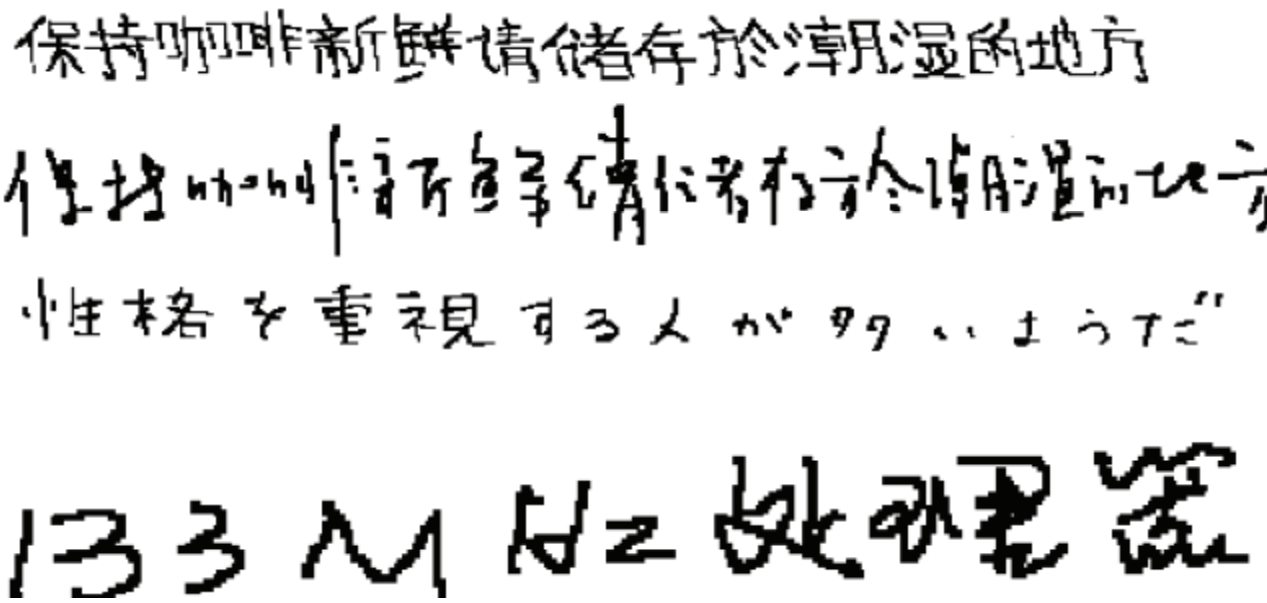
UI Issues for Embedded Recognizers

- Character Segmentation
  - Uni-stroke
  - Time threshold
  - Spatial Information/ "Ping-pong" window
  - Language Information
- Character Set switching/identification
  - Shift Key/Shift Gesture
  - Specific writing Areas for different character sets
  - Showing guide line in the writing area
- Pen Gesture integration

Prototype Recognizer Interfaces at IBM

Sentence/Page Level Handwriting Recognition

- Support more advanced devices: TransNote, CrossPad, Whiteboard, WebPad, etc.
- Geometry based segmentation combined with a language model



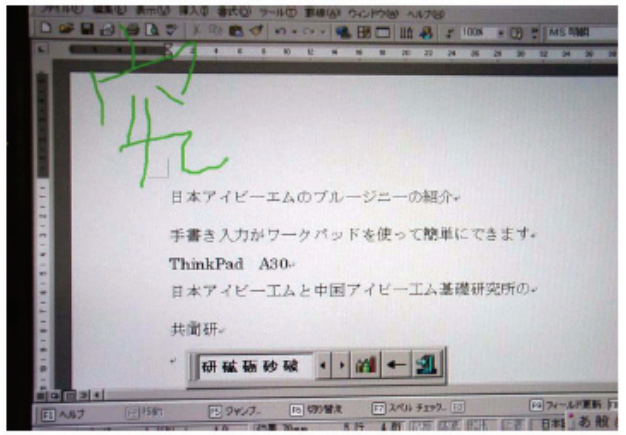
Pen/Handwriting Technology - Hardware

- ThinkScribe/CrossPad
  - Writing on paper
  - Hardware: digitizer, display,
  - memory cpu, IR/Serial, AAA battery
  - Software and API

- ThinkPad TransNote

Collaborative Input via Laptop and PDA

"Handwriting On the Move" - Input solutions for mobile laptop users



Demo

Questions ???