Automating Tactile Graphics Translation

Computer Vision

CSE 455

2010

Richard Ladner
University of Washington

Blind Scientists and Engineers

Kent Cullers, Ph.D.
Physics

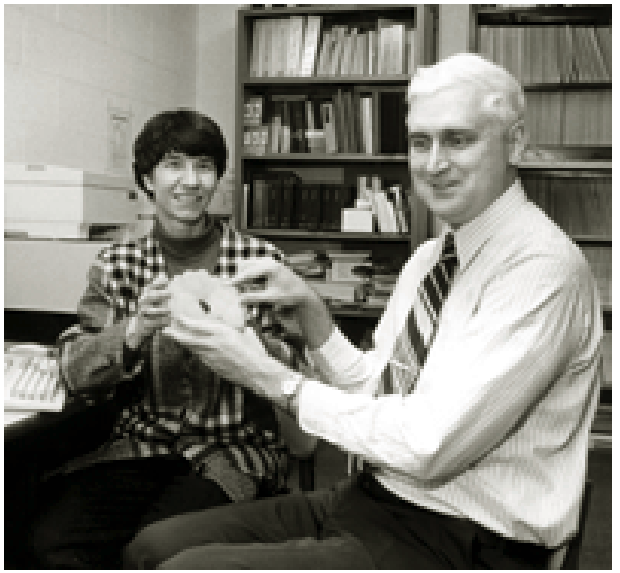
Cary Supalo
Grad Student
Chemistry

Geerat Vermeij, Ph.D.
Evolutionary Biologist

Blind Scientists and Engineers

Bill Gerrey
Electrical Engineering
Inventor

Imke Durre, Ph.D.
Atmospheric Science



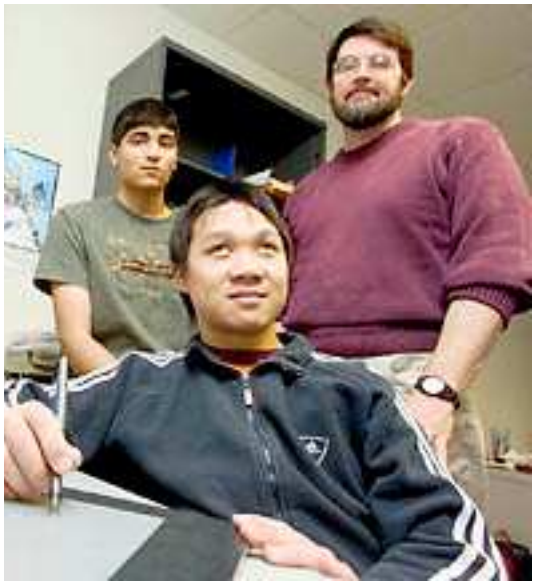
William Skawinski
Professor, Chemistry

Tactile graphics

Blind Scientists and Engineers

H. David Wohlers
Professor, Chemistry

TV Raman
Computer Science
Google



Victor Wong
EE Grad Student

Tactile graphics

Blind Scientists and Engineers

Chieko Asakawa
Computer Scientist
IBM

Hideji Nagaoka
Computer Scientist
Tsukuba U. of Tech

Katsuhito Yamaguchi
Physics
Nihon University

UW
Students

Zach Lattin
Math Major

Sangyun Hahn
Ph.D. Student
CSE

The Problem

graphics

math

text

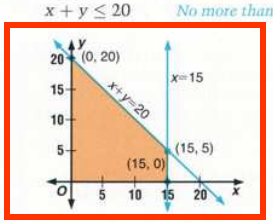
Let's use this procedure to solve the application presented at the beginning of the lesson.

Define variables.
Let x = the number of acres of crop A.
Let y = the number of acres of crop B.

Write inequalities.

$x \geq 0,\ y \geq 0$	*Acreage cannot be less than 0.*
$x \leq 15$	*No more than 15 acres of crop A are permitted.*
$x + y \leq 20$	*No more than 20 acres can be planted in all.*

Graph the system.



The constraints $x \geq 0$ and $y \geq 0$ tell you to consider only those points that are in Quadrant I.

The vertices are at $(0, 0)$, $(15, 0)$, $(15, 5)$, and $(0, 20)$.

Write an expression.
Profit equals income less costs. The profit from crop A equals $600x - 120x - 15(5.60)x$, or $396x$. The profit from crop B equals $520y - 200y - 10(5.00)y$, or $270y$. Thus, the profit function is $P(x, y) = 396x + 270y$.

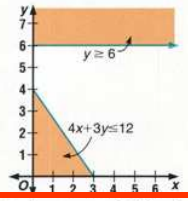
Substitute values.

$P(0,0) = 396(0) + 270(0) = 0$
$P(15,0) = 396(15) + 270(0) = 5940$
$P(15,5) = 396(15) + 270(5) = 7290$
$P(0,20) = 396(0) + 270(20) = 5400$

Answer the problem.
The maximum occurs at $(15, 5)$. Thus, Mr. Washington should plant 15 acres of crop A and 5 acres of crop B to obtain the maximum profit of $7290.

In certain circumstances, the use of linear programming is not helpful. Consider the graph at the right, based on the following constraints.

$x \geq 0$
$y \geq 0$
$y \geq 6$
$4x + 3y \leq 12$



The constraints do not define a region with any points in common in Quadrant I. When the constraints of a linear programming problem cannot be satisfied simultaneously, then **infeasibility** is said to occur. This may mean that the constraints have been formulated incorrectly, certain requirements need to be changed, or that additional resources are required before the problem can be solved.

Outline

- Tactual Perception
- Text
- Math
- Graphics
- Problems
- Thanks
- Demo

Tactile Perception

- Resolution of human fingertip: 25 dpi
- Tactual field of perception is no bigger than the size of the fingertips of two hands
- Color information is replaced by texture information
- Visual bandwidth is 1,000,000 bits per second, tactile is 100 bits per second

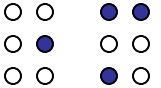
Tactile graphics

Braille

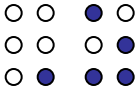
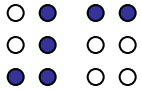
- System to read text by feeling raised dots on paper (or on electronic displays). Invented in 1820s by Louis Braille, a French blind man.

Critical fact: Fixed height and width

a  b  c  z 

and  the  with  mother 

th  ch  gh 

Z  3 

Mode characters: cap and num.

Tiger Embosser

- 20 dpi (raised dots per inch)
- 7 height levels (only 3 or 4 are distinguishable)
- Prints Braille text and graphics
- Prints dot patterns for texture
- Invented by a blind man, John Gardner

Tactile graphics

Outline

- Tactual Perception
- Text
- Math
- Graphics
- Problems
- Thanks
- Demo

Text

Let's use this procedure to solve the application presented at the beginning of the lesson.

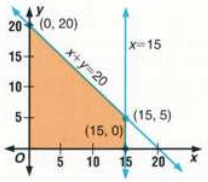
Define variables.

Let x = the number of acres of crop A.
Let y = the number of acres of crop B.

Write inequalities.

$x \geq 0,\ y \geq 0$ *Acreage cannot be less than 0.*
$x \leq 15$ *No more than 15 acres of crop A are permitted.*
$x + y \leq 20$ *No more than 20 acres can be planted in all.*

Graph the system.



The constraints $x \geq 0$ and $y \geq 0$ tell you to consider only those points that are in Quadrant I.

The vertices are at $(0, 0)$, $(15, 0)$, $(15, 5)$, and $(0, 20)$.

Write an expression.

Profit equals income less costs. The profit from crop A equals $600x - 120x - 15(5.60)x$, or $396x$. The profit from crop B equals $520y - 200y - 10(5.00)y$, or $270y$. Thus, the profit function is $P(x, y) = 396x + 270y$.

Substitute values.

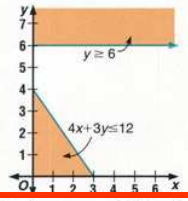
$P(0,0) = 396(0) + 270(0) = 0$
$P(15,0) = 396(15) + 270(0) = 5940$
$P(15,5) = 396(15) + 270(5) = 7290$
$P(0,20) = 396(0) + 270(20) = 5400$

Answer the problem.

The maximum occurs at $(15, 5)$. Thus, Mr. Washington should plant 15 acres of crop A and 5 acres of crop B to obtain the maximum profit of \$7290.

In certain circumstances, the use of linear programming is not helpful. Consider the graph at the right, based on the following constraints.

$x \geq 0$
$y \geq 0$
$y \geq 6$
$4x + 3y \leq 12$

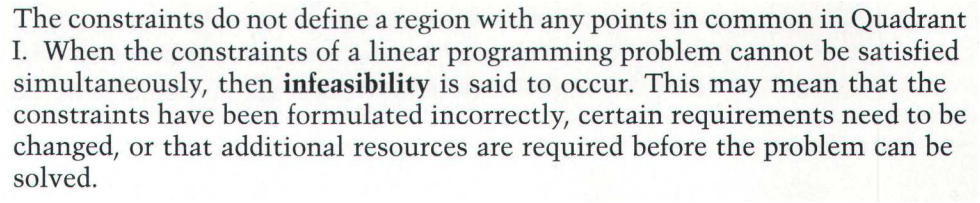


The constraints do not define a region with any points in common in Quadrant I. When the constraints of a linear programming problem cannot be satisfied simultaneously, then **infeasibility** is said to occur. This may mean that the constraints have been formulated incorrectly, certain requirements need to be changed, or that additional resources are required before the problem can be solved.

Tactile graphics

Text Translation

Text Image


The constraints do not define a region with any points in common in Quadrant I. When the constraints of a linear programming problem cannot be satisfied simultaneously, then **infeasibility** is said to occur. This may mean that the constraints have been formulated incorrectly, certain requirements need to be changed, or that additional resources are required before the problem can be solved.

Optical Character Recognition (OCR)

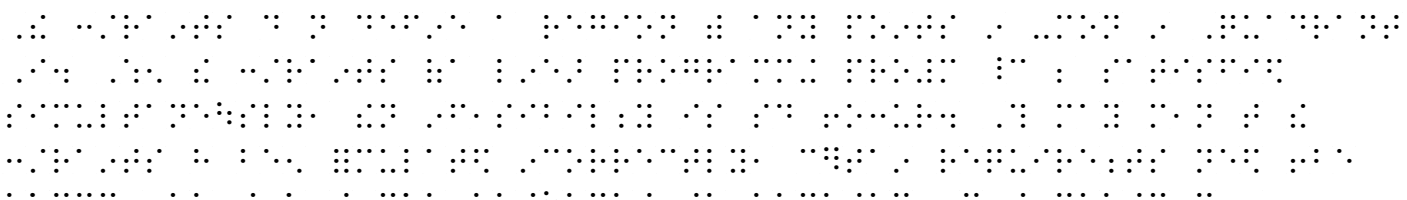
Text

```
The constraints do not define a region with any points in common in Quadrant
I. When the constraints of a linear programming problem cannot be satisfied
simultaneously, then infeasibility is said to occur. This may mean that the
constraints have been formulated incorrectly, certain requirements need to be
changed, or that additional resources are required before the problem can be
solved.
```

Braille Translation (Duxbury)

Speech Synthesis (Jaws)

Braille



Speech

Tactile graphics

Outline

- Tactual Perception
- Text
- Math
- Graphics
- Problems
- Thanks
- Demo

Math

Let's use this procedure to solve the application presented at the beginning of the lesson.

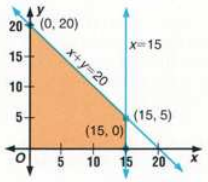
Define variables.

Let x = the number of acres of crop A.
Let y = the number of acres of crop B.

Write inequalities.

$x \geq 0,\ y \geq 0$ *Acreage cannot be less than 0.*
$x \leq 15$ *No more than 15 acres of crop A are permitted.*
$x + y \leq 20$ *No more than 20 acres can be planted in all.*

Graph the system.



The constraints $x \geq 0$ and $y \geq 0$ tell you to consider only those points that are in Quadrant I.

The vertices are at $(0, 0)$, $(15, 0)$, $(15, 5)$, and $(0, 20)$.

Write an expression.

Profit equals income less costs. The profit from crop A equals $600x - 120x - 15(5.60)x$, or $396x$. The profit from crop B equals $520y - 200y - 10(5.00)y$, or $270y$. Thus, the profit function is $P(x, y) = 396x + 270y$.

Substitute values.

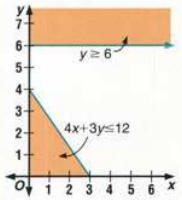
$P(0,0) = 396(0) + 270(0) = 0$
$P(15,0) = 396(15) + 270(0) = 5940$
$P(15,5) = 396(15) + 270(5) = 7290$
$P(0,20) = 396(0) + 270(20) = 5400$

Answer the problem.

The maximum occurs at $(15, 5)$. Thus, Mr. Washington should plant 15 acres of crop A and 5 acres of crop B to obtain the maximum profit of \$7290.

In certain circumstances, the use of linear programming is not helpful. Consider the graph at the right, based on the following constraints.

$x \geq 0$
$y \geq 0$
$y \geq 6$
$4x + 3y \leq 12$



The constraints do not define a region with any points in common in Quadrant I. When the constraints of a linear programming problem cannot be satisfied simultaneously, then **infeasibility** is said to occur. This may mean that the constraints have been formulated incorrectly, certain requirements need to be changed, or that additional resources are required before the problem can be solved.

Tactile graphics

Math Translation

Math Image

$$P(0,0) = 396(0) + 270(0) = 0$$
$$P(15,0) = 396(15) + 270(0) = 5940$$
$$P(15,5) = 396(15) + 270(5) = 7290$$
$$P(0,20) = 396(0) + 270(20) = 5400$$

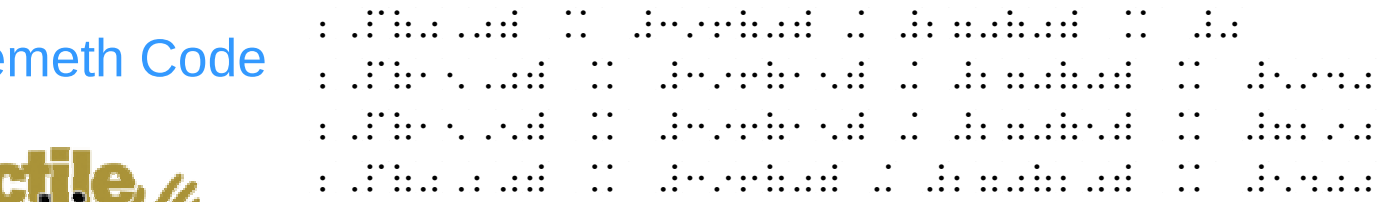
Math OCR (Infty Reader)

Latex

```
\begin{eqnarray*}
P(0,0) = 396(0) + 270(0) = 0\\
P(15,0) = 396(15) + 270(0) = 5940\\
P(15,5) = 396(15) + 270(5) = 7290\\
P(0,20) = 396(0) + 270(20) = 5400
\end{eqnarray*}
```

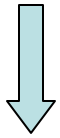
Braille Translation (Duxbury, Braille2000)

Nemeth Code

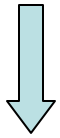


Math Translation Examples

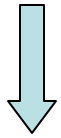
$$\sum_{i=0}^{\infty} x^i = \frac{1}{1-x}$$



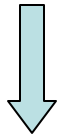
```
\sum_{i=0}^\infty x^i = \frac{1}{1-x}
```

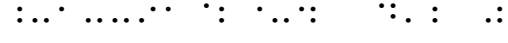


$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$



```
\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}
```





Outline

- Tactual Perception
- Text
- Math
- Graphics
- Problems
- Thanks
- Demo

Graphics

Let's use this procedure to solve the application presented at the beginning of the lesson.

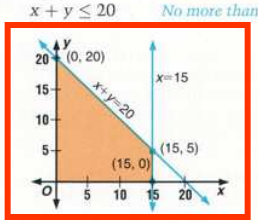
Define variables.

Let x = the number of acres of crop A.
Let y = the number of acres of crop B.

Write inequalities.

$x \geq 0,\ y \geq 0$ *Acreage cannot be less than 0.*
$x \leq 15$ *No more than 15 acres of crop A are permitted.*
$x + y \leq 20$ *No more than 20 acres can be planted in all.*

Graph the system.



The constraints $x \geq 0$ and $y \geq 0$ tell you to consider only those points that are in Quadrant I.

The vertices are at $(0, 0)$, $(15, 0)$, $(15, 5)$, and $(0, 20)$.

Write an expression.

Profit equals income less costs. The profit from crop A equals $600x - 120x - 15(5.60)x$, or $396x$. The profit from crop B equals $520y - 200y - 10(5.00)y$, or $270y$. Thus, the profit function is $P(x, y) = 396x + 270y$.

Substitute values.

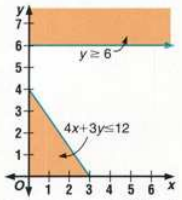
$P(0,0) = 396(0) + 270(0) = 0$
$P(15,0) = 396(15) + 270(0) = 5940$
$P(15,5) = 396(15) + 270(5) = 7290$
$P(0,20) = 396(0) + 270(20) = 5400$

Answer the problem.

The maximum occurs at $(15, 5)$. Thus, Mr. Washington should plant 15 acres of crop A and 5 acres of crop B to obtain the maximum profit of \$7290.

In certain circumstances, the use of linear programming is not helpful. Consider the graph at the right, based on the following constraints.

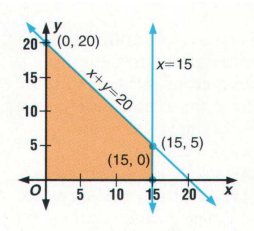
$x \geq 0$
$y \geq 0$
$y \geq 6$
$4x + 3y \leq 12$



The constraints do not define a region with any points in common in Quadrant I. When the constraints of a linear programming problem cannot be satisfied simultaneously, then **infeasibility** is said to occur. This may mean that the constraints have been formulated incorrectly, certain requirements need to be changed, or that additional resources are required before the problem can be solved.

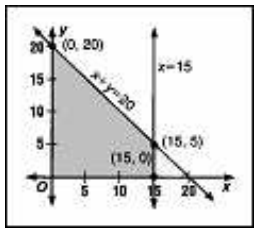
Tactile graphics

Graphic Translation



original scanned image

preprocess



clean image

text extract

pure graphic

location file

```
                    <LocationInformation>
<NumLabels>16</NumLabels>
<Resolution>100.000000</Resolution>
<ScaleX>1.923077</ScaleX>
<ScaleY>1.953125</ScaleY>
-
                    <Label>
<x1>121</x1>
<y1>45</y1>
<x2>140</x2>
<y2>69</y2>
<Alignment>0</Alignment>
<Angle>3.141593</Angle>
</Label>
```

text image

y
(0, 20)
x=15
15
10
5
O
x
5
10
15
20
20

x+y=20

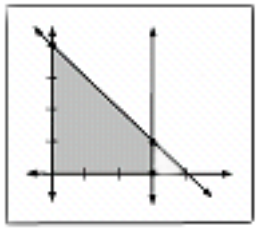
(15, 0)
(15, 5)

Tactile graphics

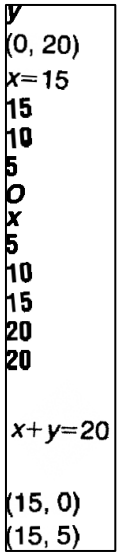
Graphic Translation

location file

```
                    <LocationInformation>
<NumLabels>16</NumLabels>
<Resolution>100.000000</Resolution>
<ScaleX>1.923077</ScaleX>
<ScaleY>1.953125</ScaleY>
-
                    <Label>
<x1>121</x1>
<y1>45</y1>
<x2>140</x2>
<y2>69</y2>
<Alignment>0</Alignment>
<Angle>3.141593</Angle>
</Label>
```



pure graphic

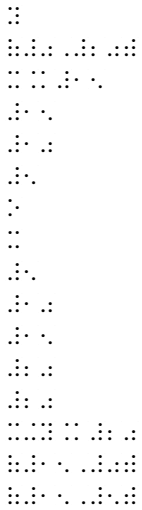


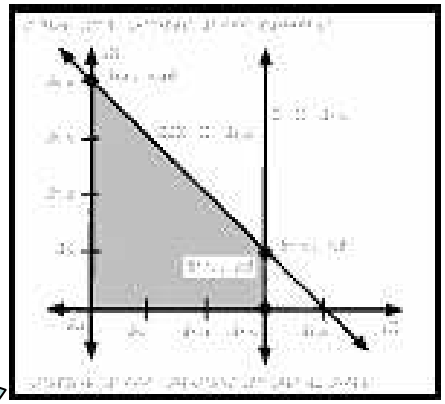
text image

text

```
y
(0,20)
x=15
15
10
5
0
x
5
10
15
20
20
x+y=20
(15,0)
(15,5)
```

Braille

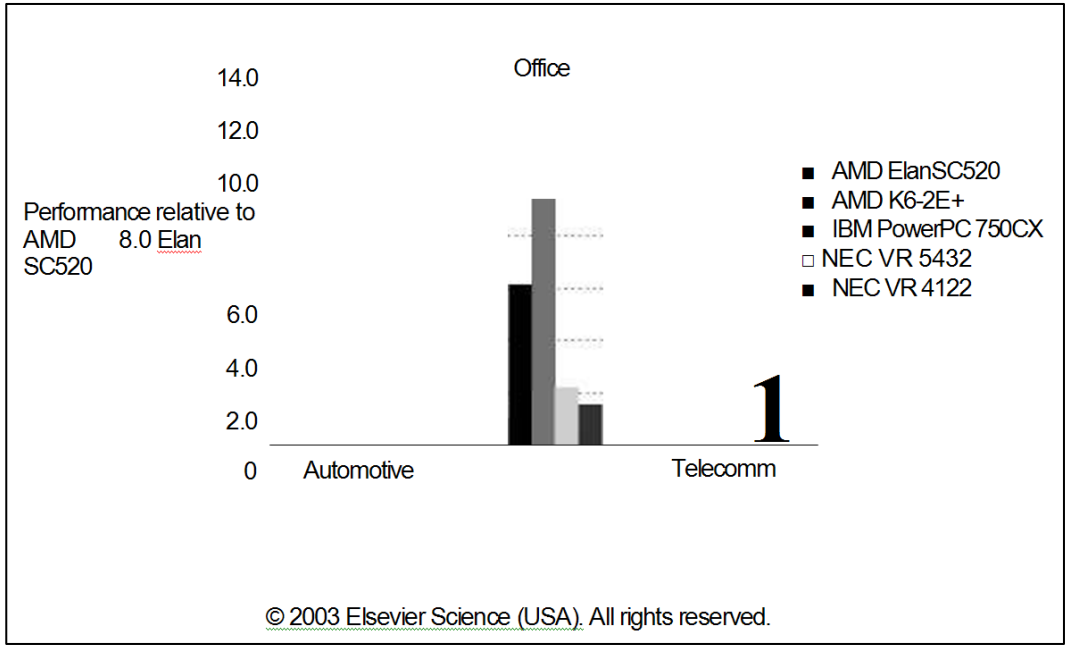




Tactile graphics

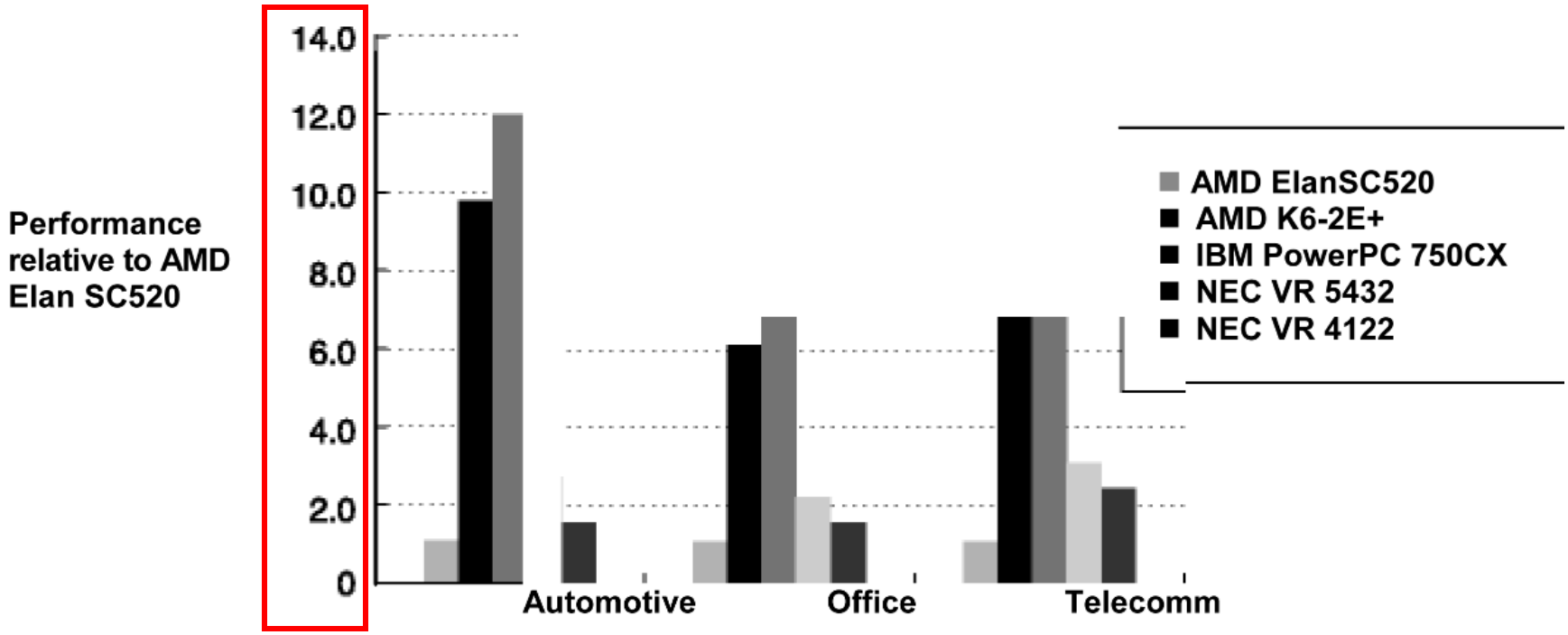
Finding Text

- Why not just use standard optical character recognition (OCR)?
  - OCR is not effective for graphical images.



ABBYY FineReader 7.0 Professional Edition

More OCR



Find Text Letters

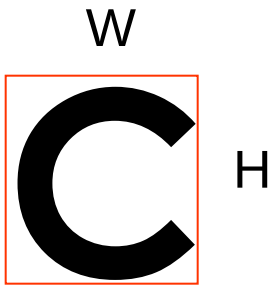
- Uses the following principles
  - Text in an image is usually in one font
  - Fonts are designed to have a uniform density at a distance.
  - In the absence of noise an individual letter tends to be connected component of one color. Exceptions are i and j.
- Use machine learning to determine which connected components are letters.

Tactile graphics

Features

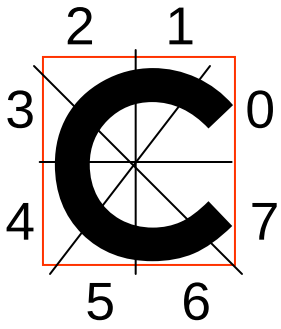
Century Gothic

W = width of bounding box
H = height of bounding box
A = area of bounding box
R_i = i-th radial slice density



$A = W \bullet H$

R_i = number of black pixels in i-th slice where a slice is an angle of 360/n. The total number of slices is n.



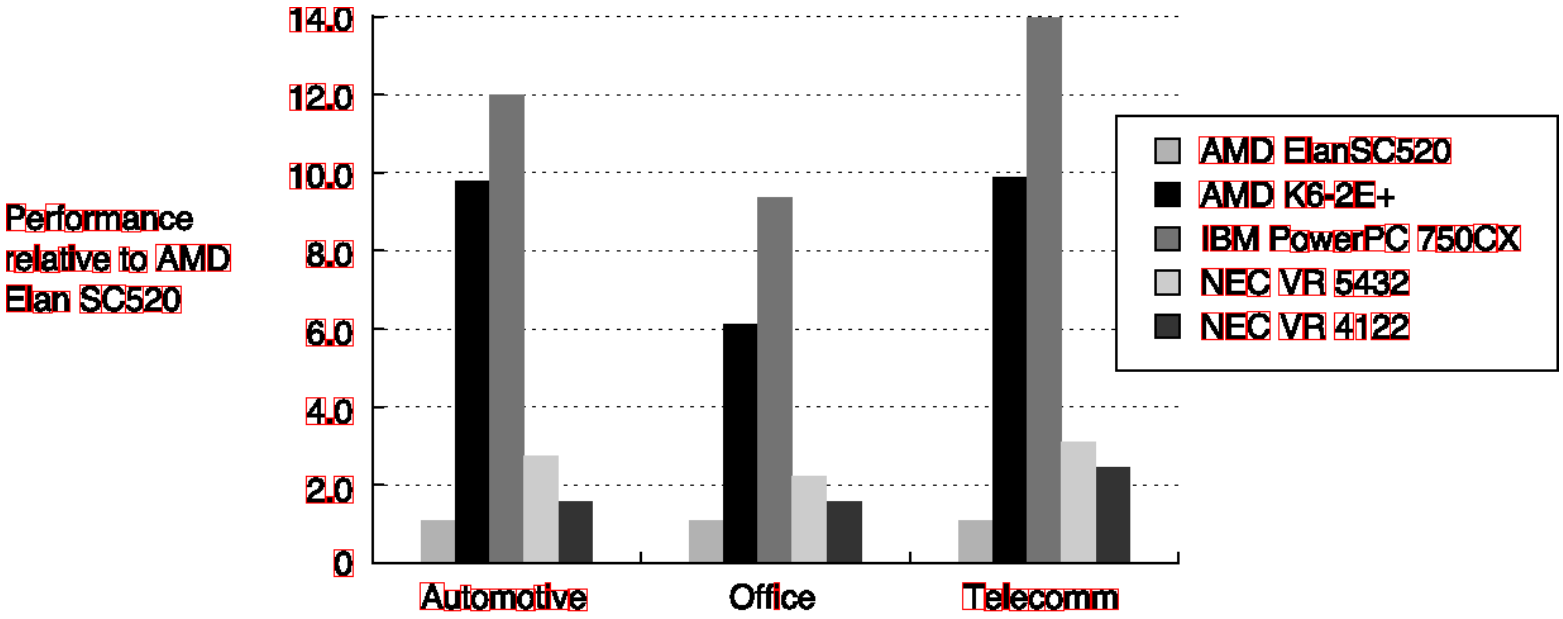
Center is center of mass of black pixels

Machine Learning

- Training:
  - Sample the connected components and compute their features.
  - Use these features to train a Support Vector Machine (SVM).
- Finding:
  - For a new connected component compute its features.
  - Feed these features into the SVM.

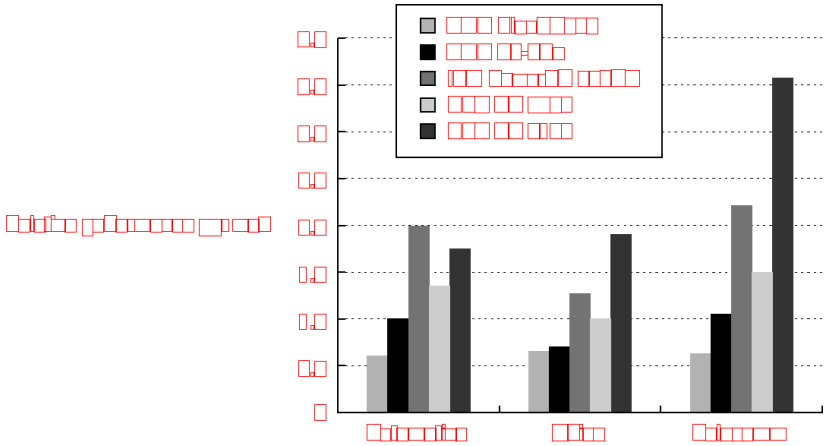
Tactile graphics

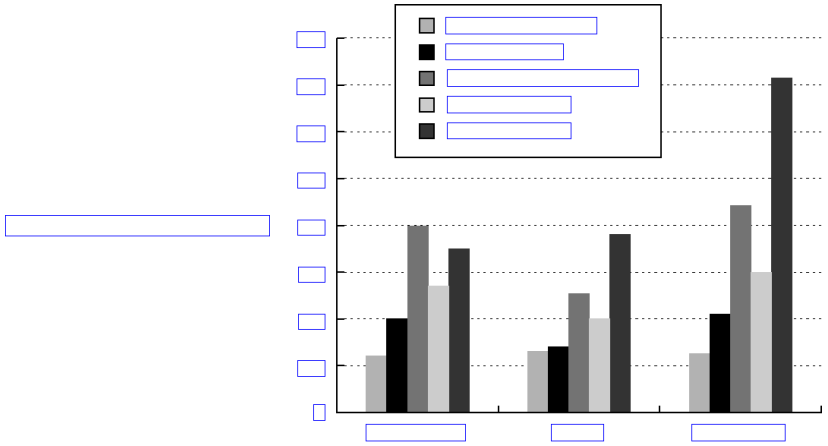
Example



Trained on a different images from the same book.
About 200 letters in the training set.

Find Text Blocks





Group characters logically

- Extracting a set of isolated characters from an image is insufficient
  - Need groups of Braille characters for easier placement
- Challenges
  - Text can be at many angles
  - Individual characters may be aligned along multiple axes

Tactile graphics

Our approach

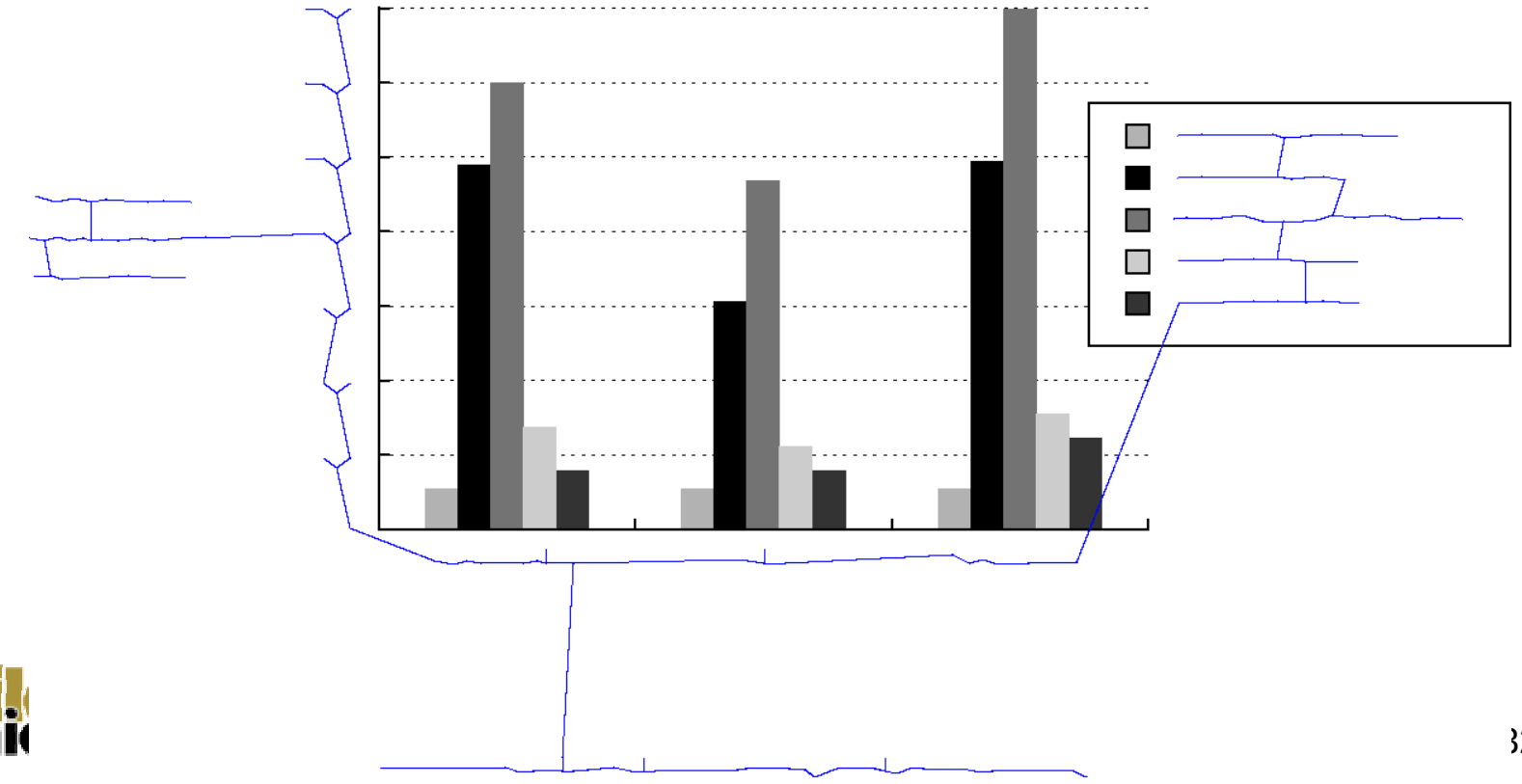
- Step 1: User provides training set
  - Software examines defining features
- Step 2: Automatically find similar groups in remaining images

A. Minimum spanning tree
B. Discard useless edges
C. Discard inconsistent edges
D. Create merged groups

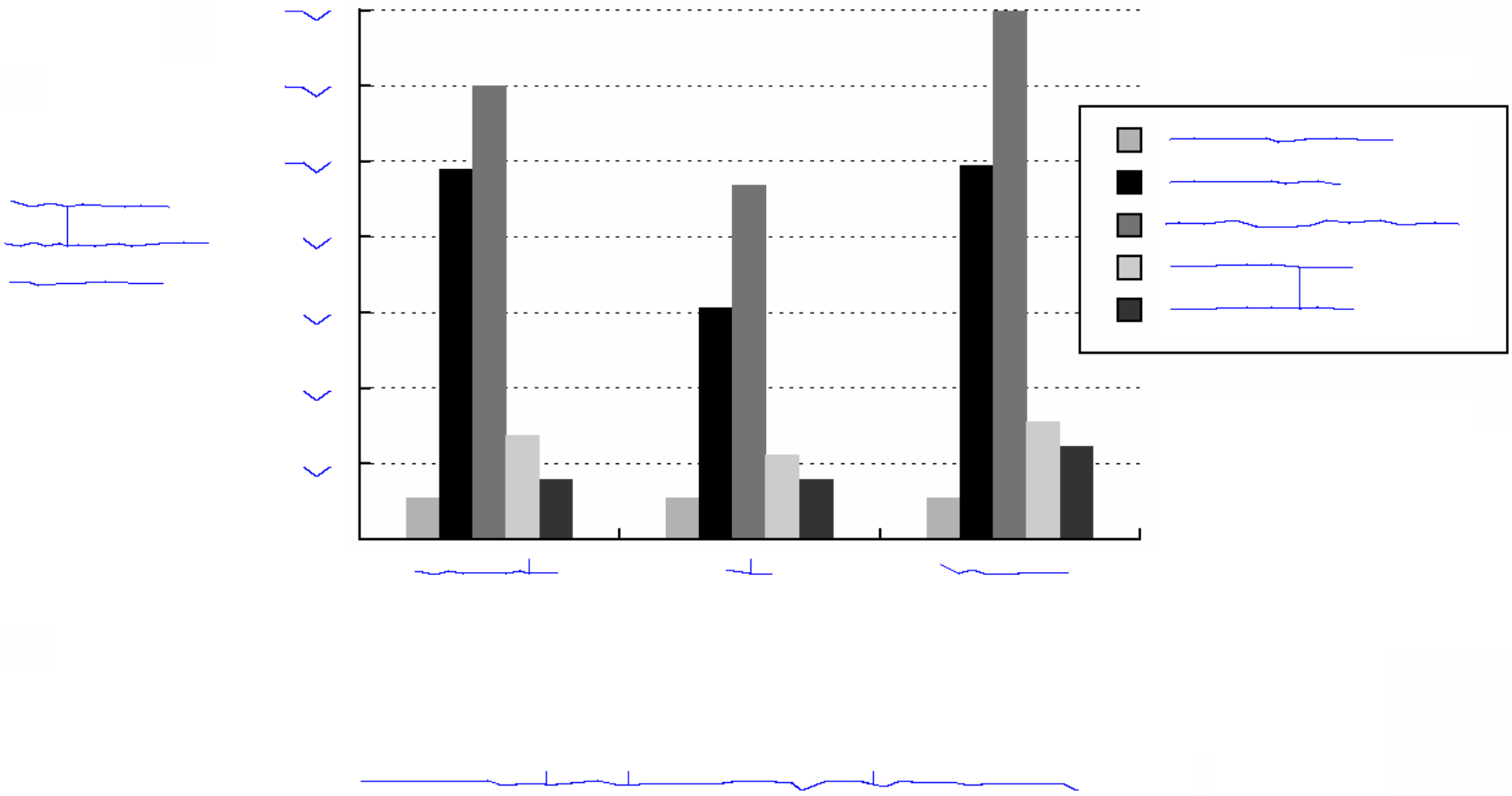
Tactile graphics

Minimum spanning tree (1)

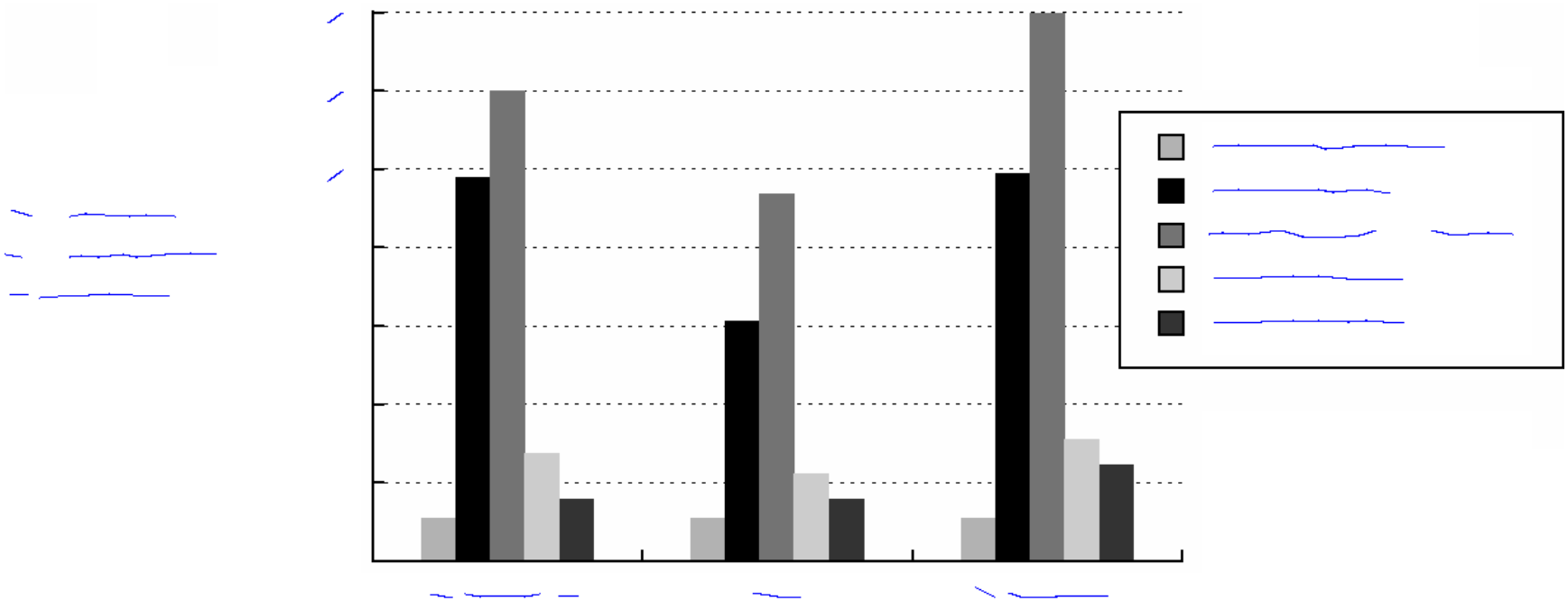
Treat the centroid of each connected component as a node



Discard useless edges (2)

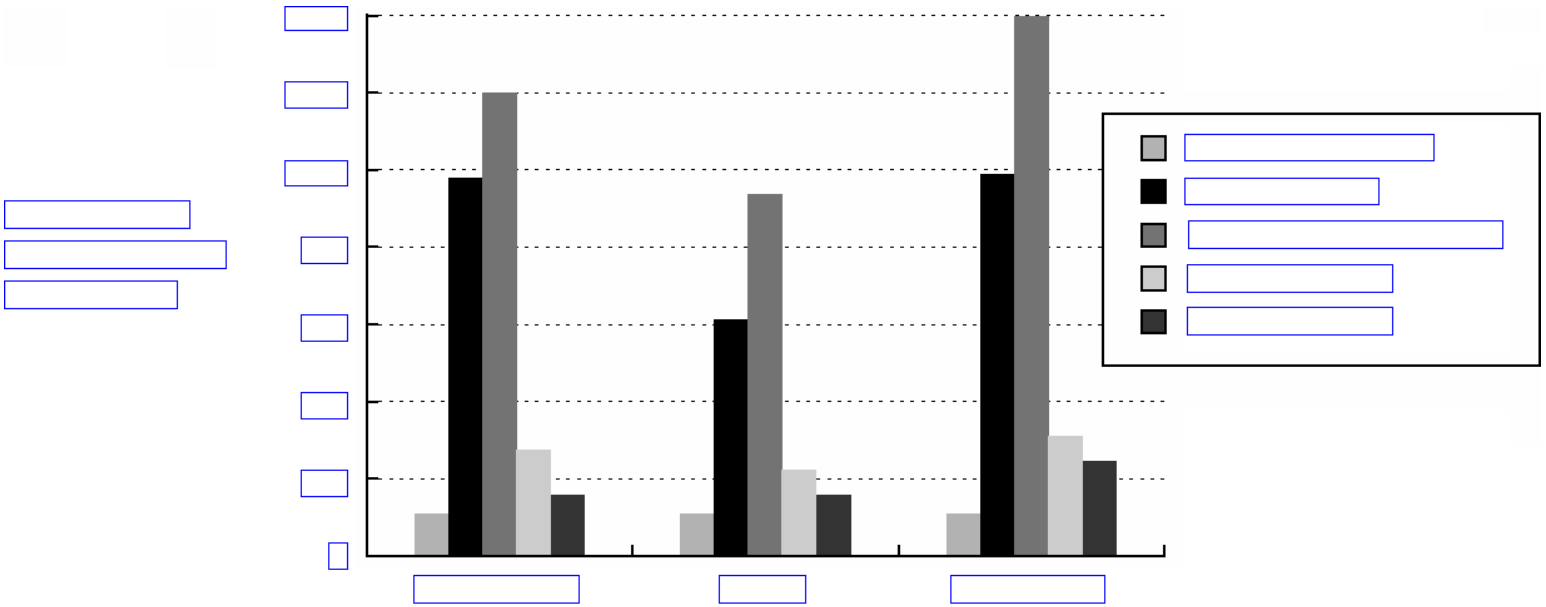


Discard inconsistent edges (3)



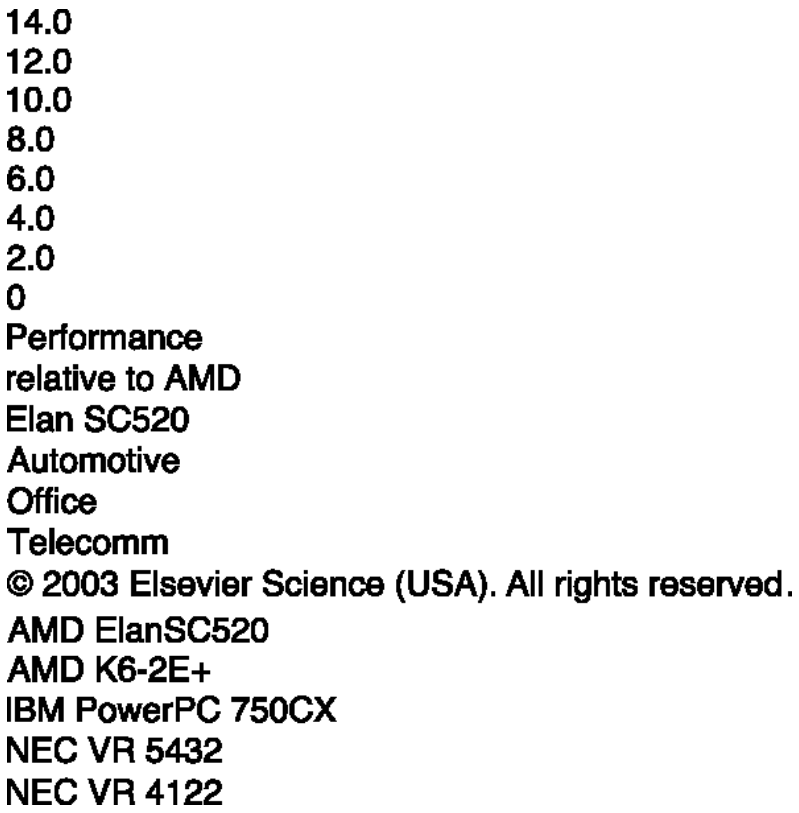
Final merge step (4)

Merge only if the resultant group is consistent



OCR on Text Image

Image of text boxes



OCR →

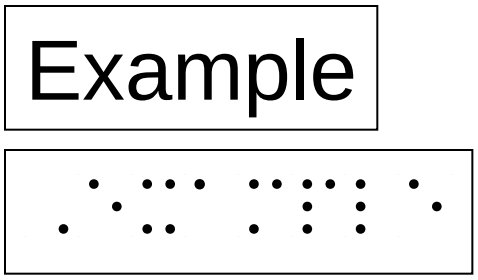
Text

14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
Performance
relative to AMD
Elan SC520
Automotive
Office
Telecomm
© 2003 Elsevier Science (USA). All rights reserved.
AMD ElanSC520
AMD K6-2E+
IBM PowerPC 750CX
NEC VR 5432
NEC VR 4122

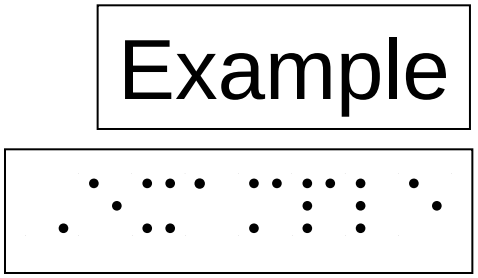
Tactile graphics

Braille Placement

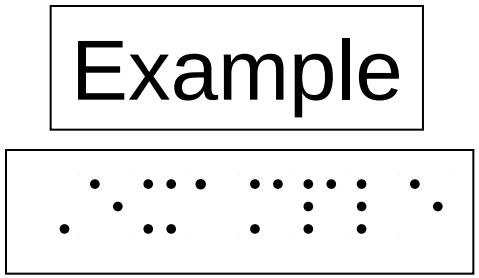
- Text boxes of Braille will be of different size than the original text boxes
  - Mode characters
  - Contractions
  - Braille is fixed width



Left justified

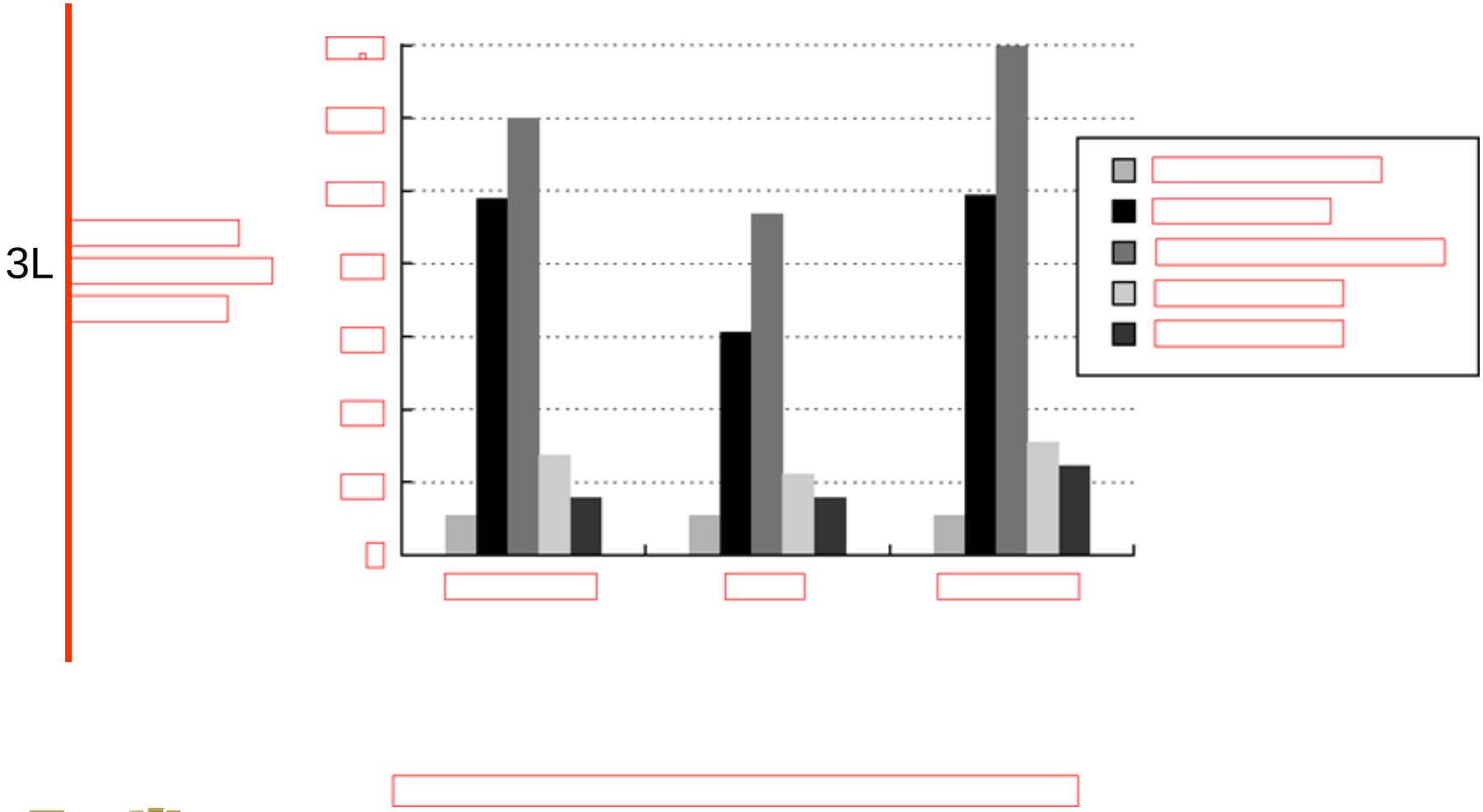


Right justified

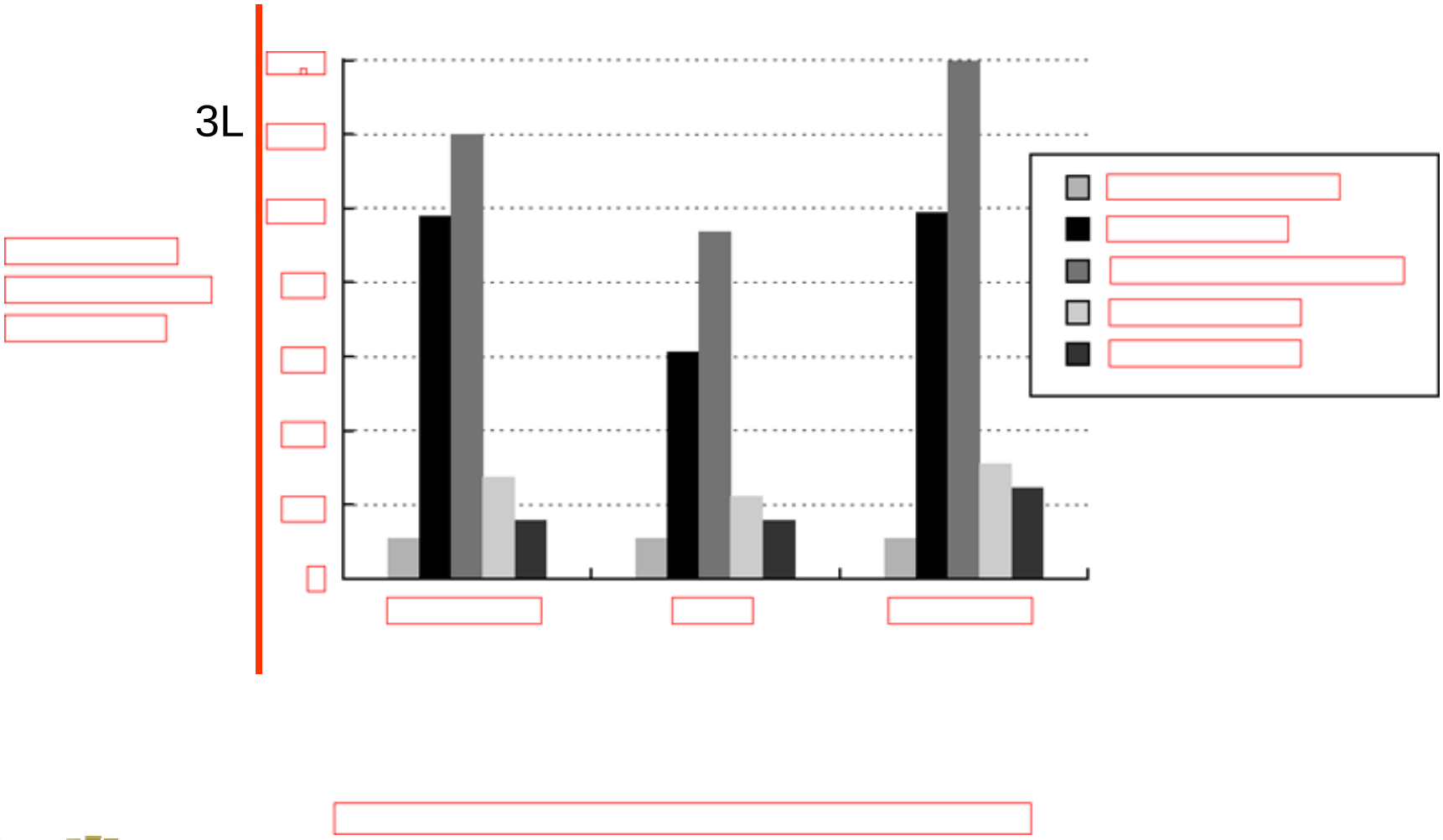


Centered

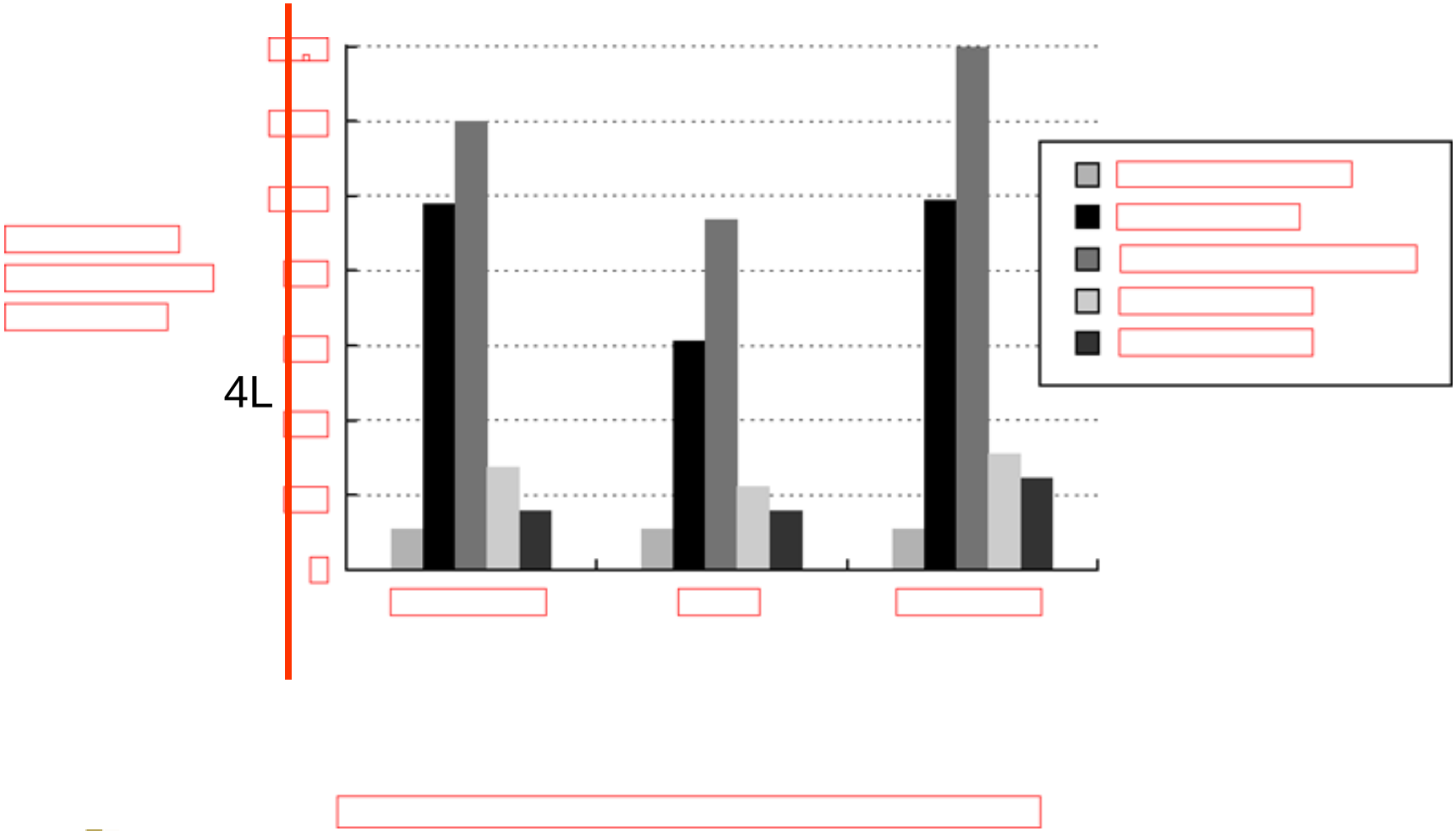
Example Plane Sweep



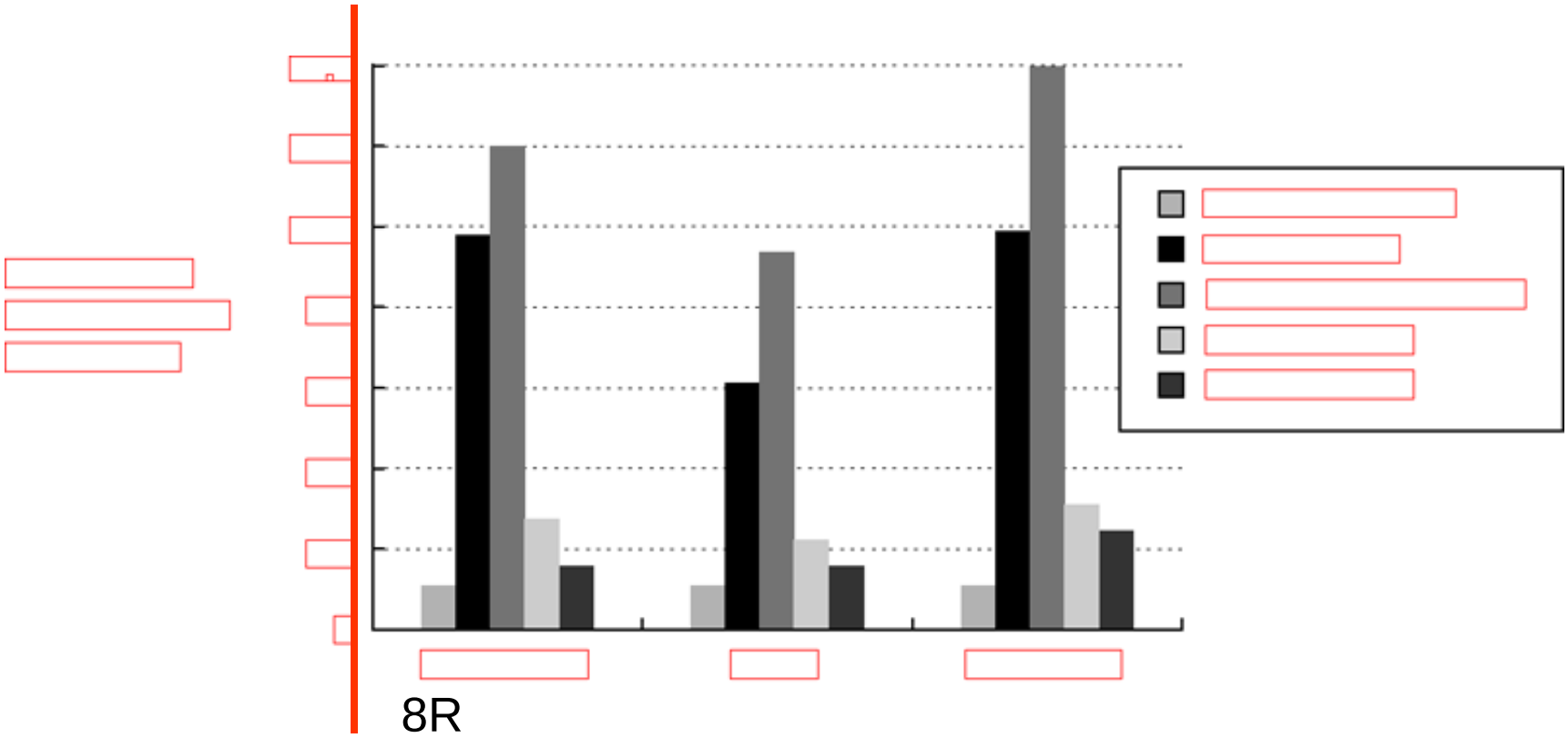
Example Plane Sweep

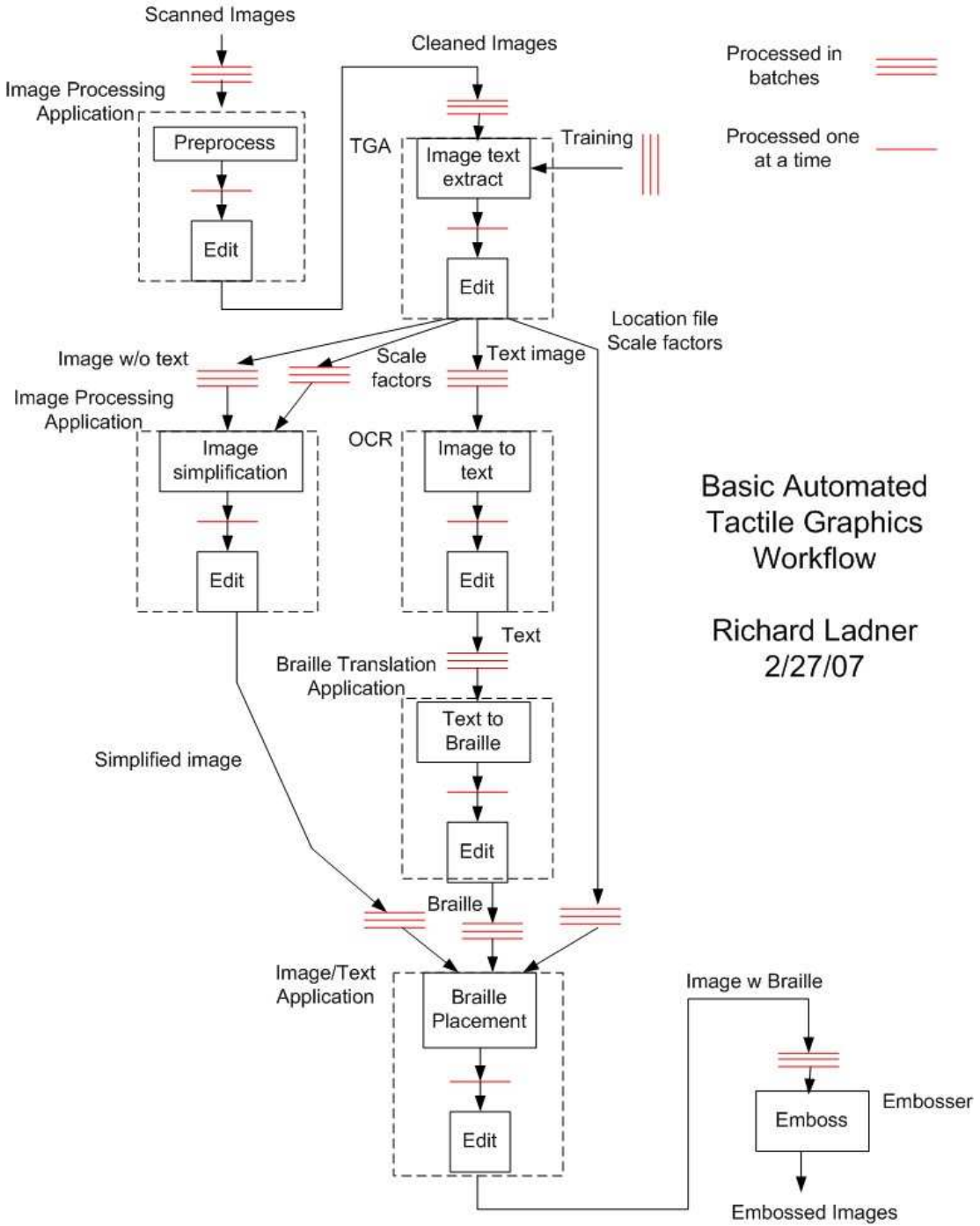


Example Plane Sweep



Example Plane Sweep



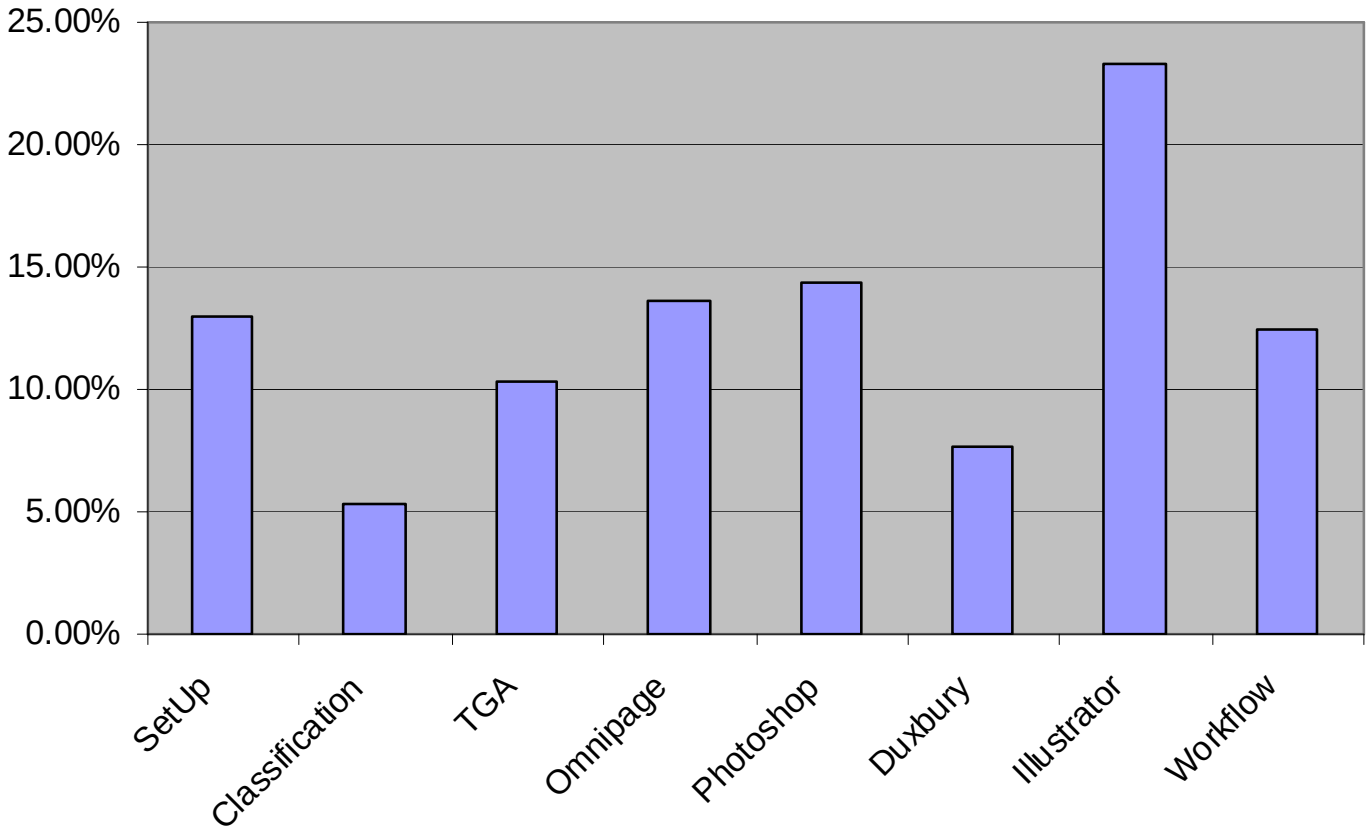

Scanned Images
Cleaned Images
Processed in batches
Processed one at a time
Image Processing Application
Preprocess
Edit
TGA
Image text extract
Training
Edit
Location file Scale factors
Image w/o text
Scale factors
Text image
Image Processing Application
Image simplification
Edit
OCR
Image to text
Edit
Text
Braille Translation Application
Text to Braille
Edit
Simplified image
Braille
Image/Text Application
Braille Placement
Edit
Image w Braille
Emboss
Embosser
Embossed Images
Basic Automated Tactile Graphics Workflow
Richard Ladner
2/27/07

Available Books

- Computer Architecture: A Quantitative Approach, 3rd Edition
  25 minutes per figure (230 figures)
- Advanced Mathematical Concepts, Precalculus with Applications
  6.3 minutes per figure (1,080 figures)
- An Intoduction to Modern Astrophysics
  10.2 minutes per figure (467 figures)
- Discrete Mathematical Structures
  8.8 minutes per figure (598 figures)
- Introduction to the Theory of Computation, 2nd Edition
  13.3 minutes per figure (180 figures)

Tactile graphics

Work Balance



TGA Workflow

- Advantages
  - Much faster production
  - Batch processing instead of one figure at a time
  - Much tedious work is avoided
- Disadvantages
  - May be of lower quality than custom translation
  - A lot of technology needs to be mastered

Tactile graphics

One-offs vs. Mass Production

1916 Woods
Dual Power

1906 Reo

Model T

Tactile graphics

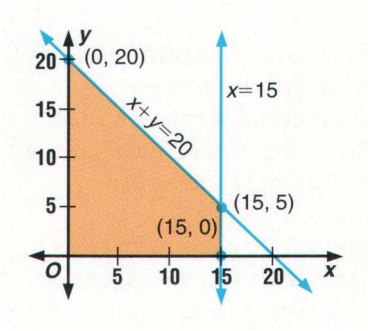
Outline

- Text
- Math
- Graphics
- Workflow
- Problems
- Thanks
- Demo

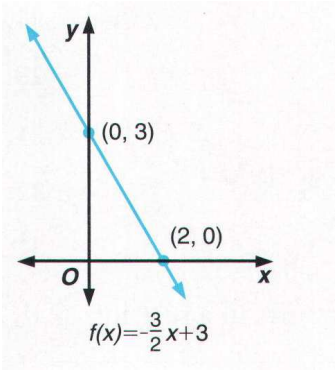
Problem solving

- Each book present a set of unique problems.
- We consider a few today
  - Classification of figures
  - Legends and colors
  - Text at an angle
  - Math in figures
  - Grids

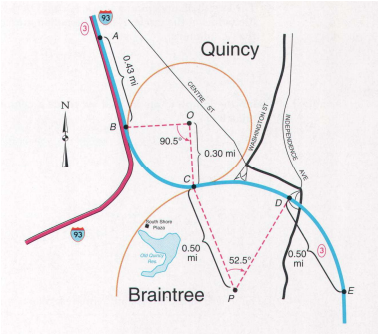
Classes



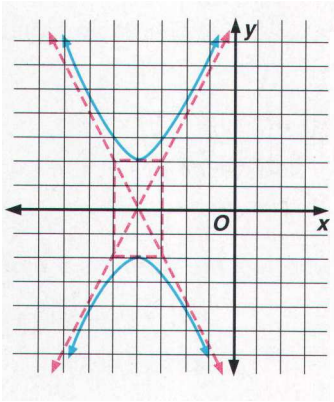
Clean area
83



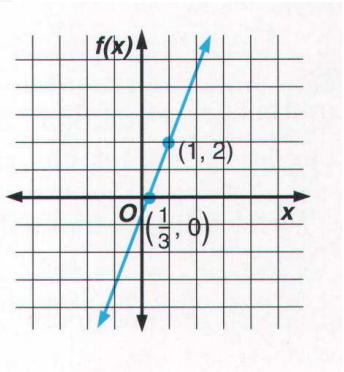
Clean lines
648



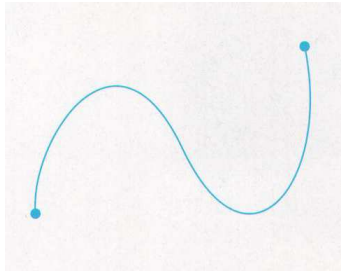
Complex
62



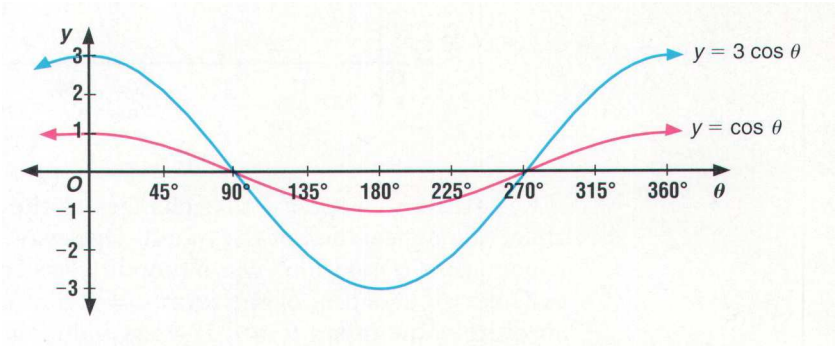
Grid clean
15



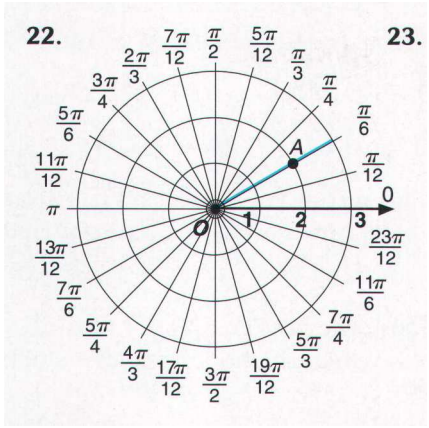
Grid overlap
113



No text
41



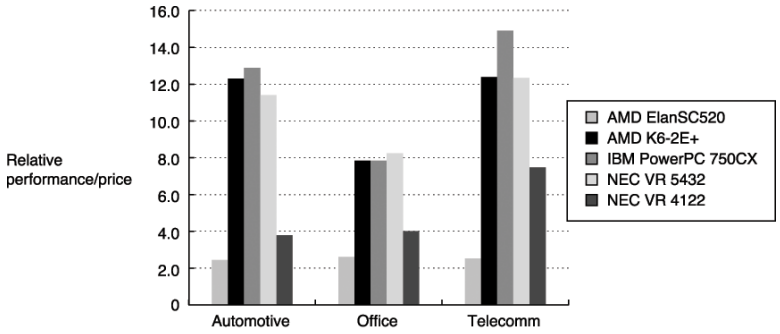
Overlapped text
94

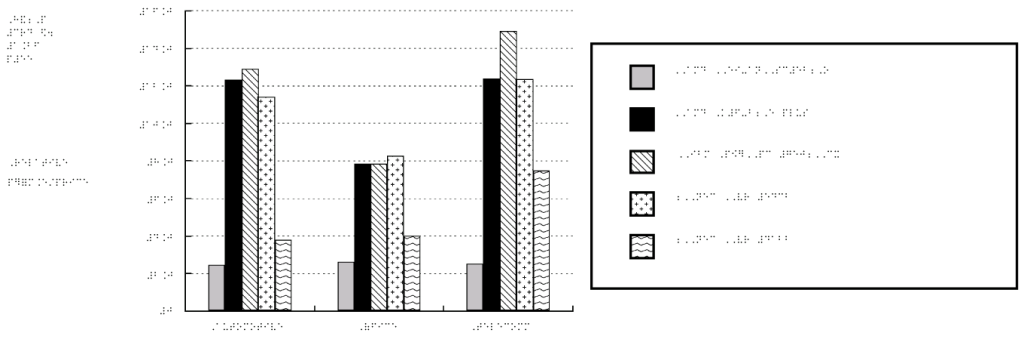


Radial
53

Legends and Colors

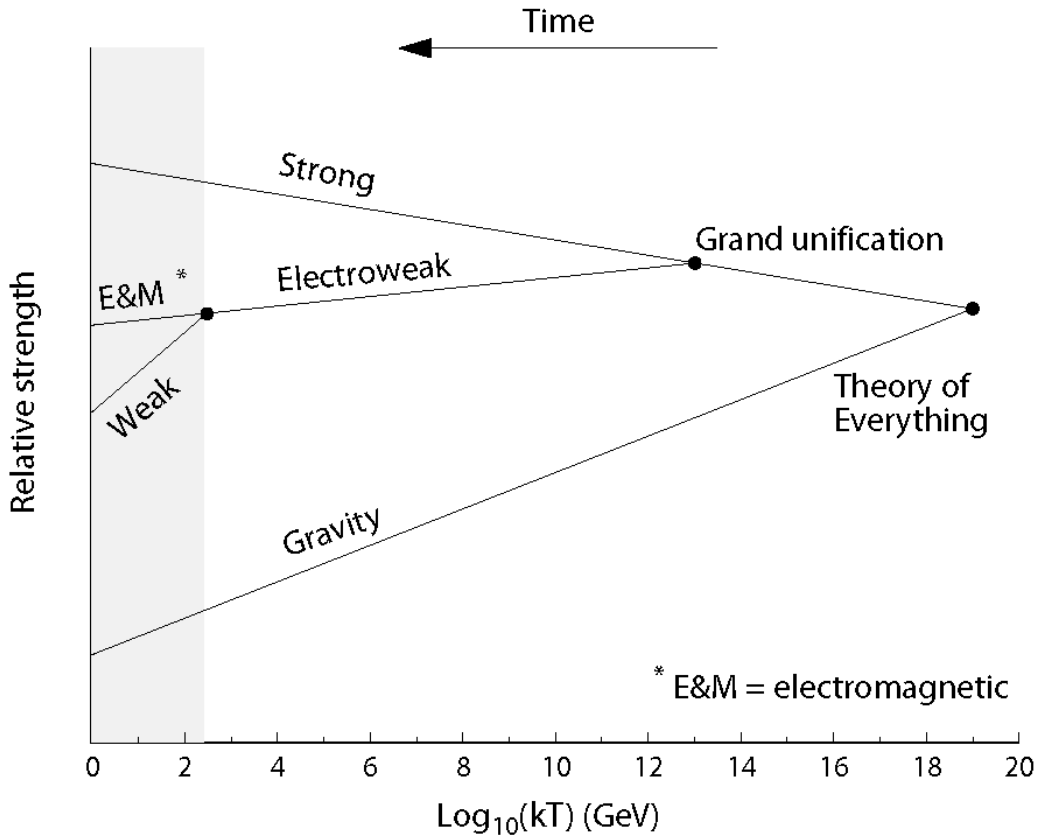
- Legends may have to be enlarged.
- Colors may have to be replaced with textures.



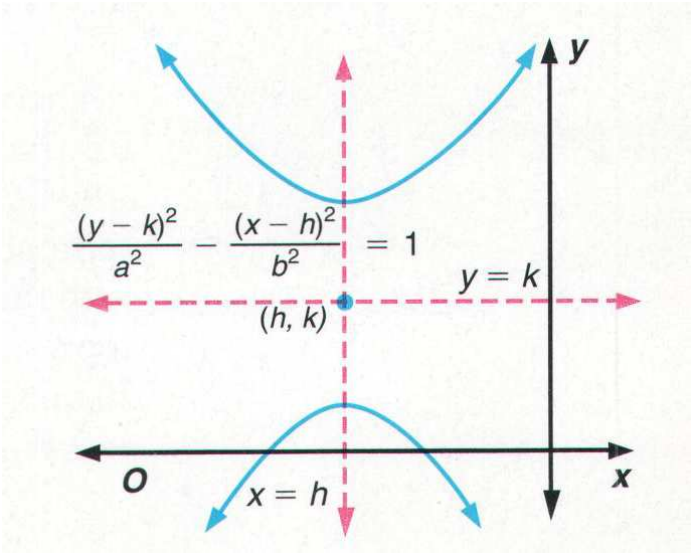


Angled Text

- Braille should be printed horizontally.



Math – Infty Reader



$$\frac{(y-k)^2}{a^2} - \frac{(x-h)^2}{b^2} = 1$$

$y = k$

y

x

(h, k)

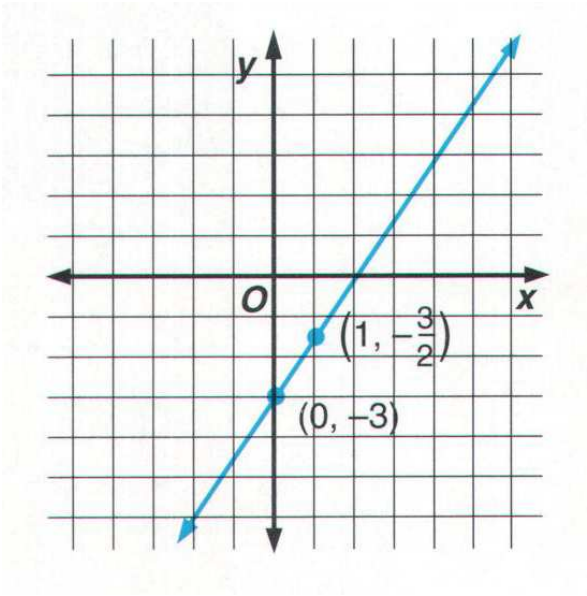
O

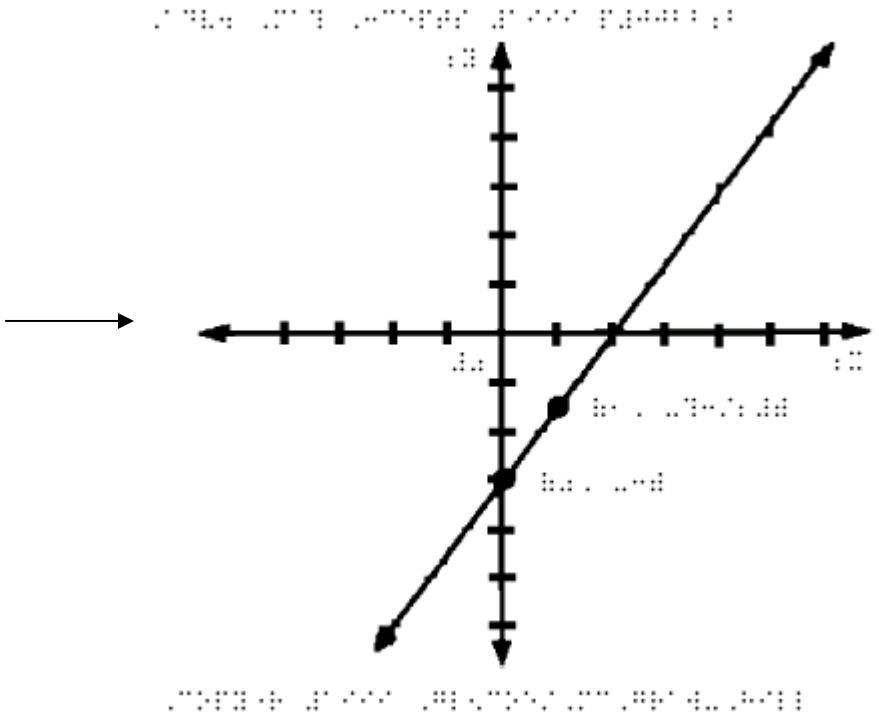
$x = h$

Extracted Math Image

Grids

- Grids may not work well in tactile form.



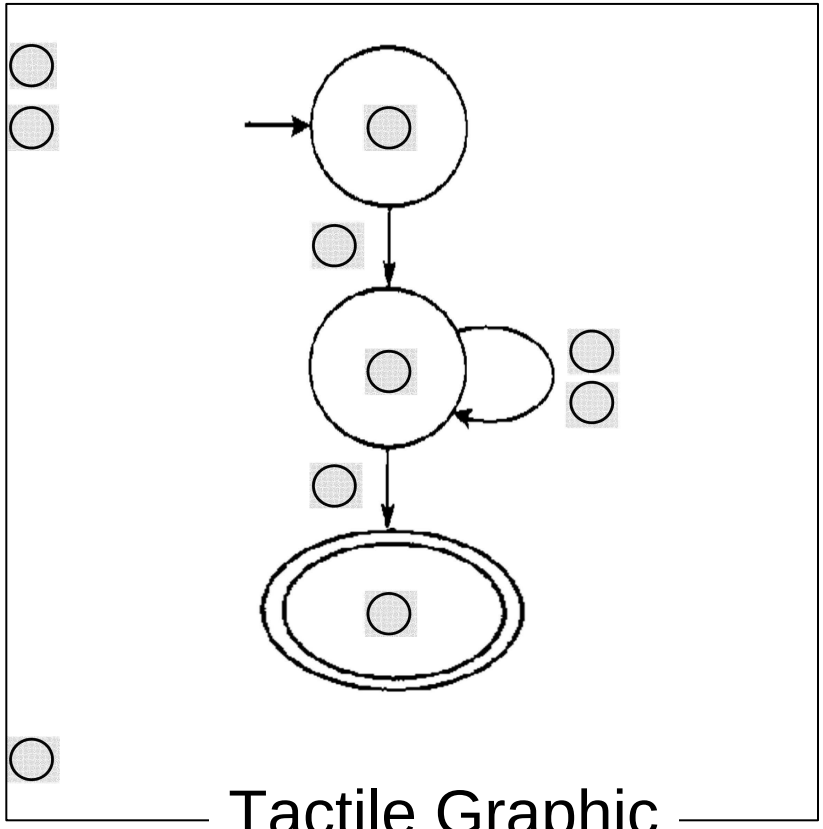


TGA Technology

- Tactile Graphic Assistant
  - C++
  - Machine Learning (Support Vector Machine)
    - Learns features of text from positive and negative examples.
  - Computational Geometry
    - Text justification
  - Free executable
  - Licensable source code

New Direction:
Digital Pen Tactile Graphic

Digital Pen



Tactile Graphic

Technology of the Future

- Electro-rheological fluid displays

Outline

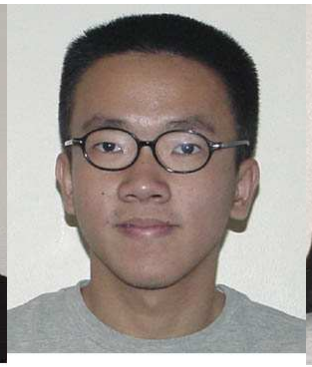
- Text
- Math
- Graphics
- Workflow
- Problems
- Thanks
- Demo

Tactile graphics

CSE Undergraduate Students

Terri Moore

2004



Andy Jaya

2004

Eileen Hash

2004

Jacob Christensen

2004

Satria Krisnandi

2005

Matthew Renzelmann

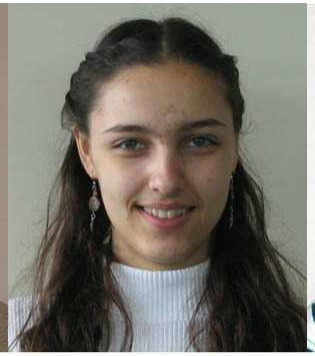
2005

Mahalakshmi Ramasamy

2005

Jack Hebert

2005



Veneta Tashev

2006

Cian Malone

2007

Dana Wen

2008

Kris Weber

2008

Current Undergraduate Student

Josh Scotland

CSE Graduate Students

Sahngyun Hahn

Chandrika Jayant

Tactile graphics

Thanks To

- Dan Comden
- Sheryl Burgstahler
- Raj Rao
- Melody Ivory
- Ethan Katz-Basset
- Zach Lattin
- Stuart Olsen
- Many others

Tactile graphics

Thanks To

Royalty Research Fund

Tactile graphics

DEMO