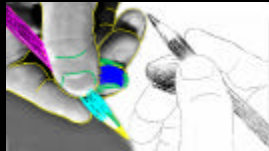


# Decoupling Strokes and High-Level Attributes for Interactive Traditional Drawing



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## Overview

- Input photo
- User draws strokes
- Semi-automatic tone
- High-level control



## Motivations for decoupling

- Strokes have multiple roles
  - Outline
  - Tone
  - Texture
  - High-level qualities, e.g. precision
- Simultaneously managing them all is challenging

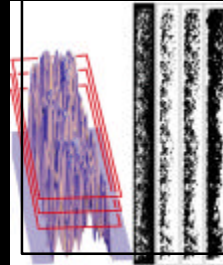


Pablo Picasso, 1954

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## Motivation within NPR

- Separate “guts” of rendering & user control
- Provide “relevant” degrees of freedom



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## Previous work

- Pen & Ink illustration
  - [Salisbury et al.]
  - High-level control, simple stroke (orientation texture)
- Pencil models
  - E.g. [Sousa & Buchanan]
  - Fine stroke, no high-level
- Digital engraving
  - [Ostromoukhov]
  - Engraving only

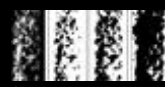


Motivation - Stroke - Equilibration - Decomposition - Results

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## Contributions & Plan

- Stroke model
- Rapid equilibration
- High-level decoupling
- Implementation & results



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### Review of Thresholding

- Digital halftoning, digital engraving [Ost. 99]
- Threshold structure
  - can be seen as height field or gray-scale

Stroke – Equilibration – Decoupling – Results 7

### Review of Thresholding

- Digital halftoning, digital engraving [Ost. 99]
- Threshold structure
  - can be seen as height field or gray-scale
- Truncate at target tone level

Stroke – Equilibration – Decoupling – Results 8

### Review of Thresholding

- Digital halftoning, digital engraving [Ost. 99]
- Threshold structure
  - can be seen as height field or gray-scale
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Stroke – Equilibration – Decoupling – Results 9

### Review of Thresholding

- Digital halftoning, digital engraving [Ost. 99]
- Threshold structure
  - can be seen as height field or gray-scale
- Truncate at target tone level

Stroke – Equilibration – Decoupling – Results 10

### Review of Thresholding

- Digital halftoning, digital engraving [Ost. 99]
- Flat histogram is crucial for faithful tone reproduction
  - All values must be represented equally

Stroke – Equilibration – Decoupling – Results 11

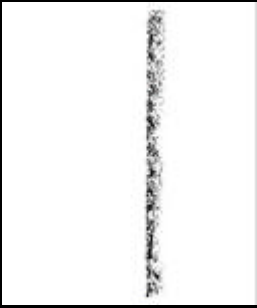
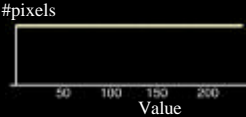
### Extension to arbitrary strokes

- Scan a pencil stroke

Stroke – Equilibration – Decoupling – Results 12

### Extension to arbitrary strokes

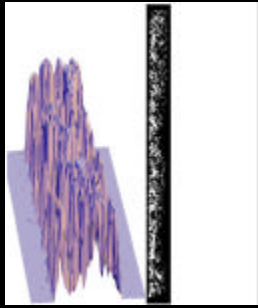
- Scan a pencil stroke
- Equilibrate (flatten histogram)

Stroke – Equilibration – Decoupling – Results 12

### Thresholding Stroke Model

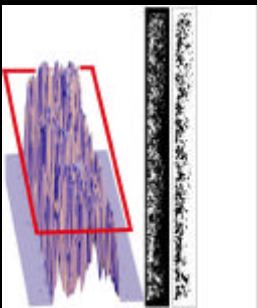
- Scan a pencil stroke
- Equilibrate (flatten histogram)
- Consider it as threshold structure



Stroke – Equilibration – Decoupling – Results 14

### Thresholding Stroke Model

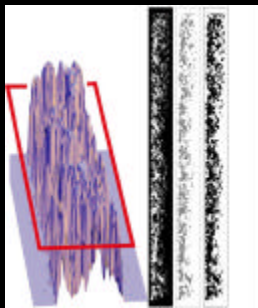
- Scan a pencil stroke
- Equilibrate (flatten histogram)
- Consider it as threshold structure
- Truncate at target tone level



Stroke – Equilibration – Decoupling – Results 15

### Thresholding Stroke Model

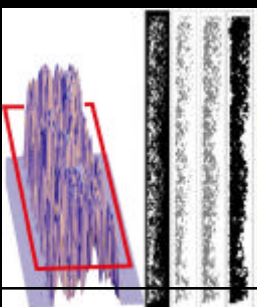
- Scan a pencil stroke
- Equilibrate (flatten histogram)
- Consider it as threshold structure
- Truncate at target tone level



Stroke – Equilibration – Decoupling – Results 16

### Thresholding Stroke Model

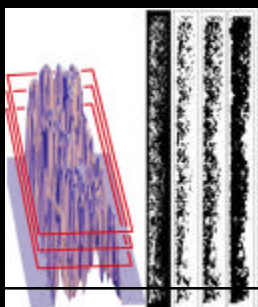
- Scan a pencil stroke
- Equilibrate (flatten histogram)
- Consider it as threshold structure
- Truncate at target tone level



Stroke – Equilibration – Decoupling – Results 17

### Why does it work?

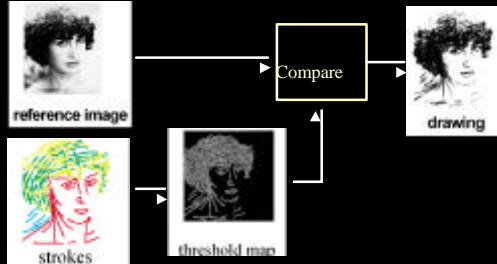
- Grey level on scan can be seen as macro-probability of graphite deposit
- Similarity between pencil & lithography
- Works for a variety of traditional media (charcoal, pencil, etching, etc.)



Stroke – Equilibration – Decoupling – Results 18

## Thresholding basic technique

- Render threshold map and compare to target tone
- Strokes and tone are decoupled!



Stroke - Equilibration - Decoupling - Results 19

## Smudging

- Spread graphite particles
- Rubbing a piece of paper or finger



Without Smudging

With Smudging (simulation)

Stroke - Equilibration - Decoupling - Results 20

## Smudging (and antialiasing)

- Smooth thresholding function instead of binary comparison



output tone

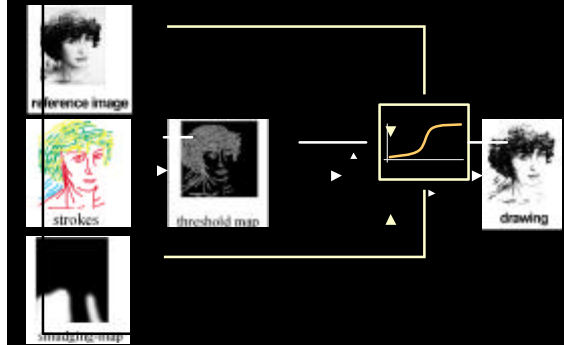
target tone - threshold

output tone

target tone - threshold

Stroke - Equilibration - Decoupling - Results 21

## Thresholding with smudging



Stroke - Equilibration - Decoupling - Results 22

## Plan

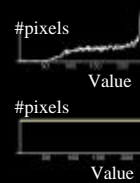
- Stroke model
- Rapid equilibration
- High-level decoupling
- Implementation & results



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## Threshold Map Equilibration

- Crucial for tonal fidelity
- Previous work
  - Iterative approach: Trial and error
  - Too slow for us
- A single stroke has a flat histogram
- We have to correct only for overlap



Stroke - Equilibration - Decoupling - Results 24

### Probabilistic study

- One stroke : flat histogram

Stroke1      Stroke2      Histogram of stroke 1 (or 2)

Stroke - Equilibration - Decoupling - Results 25

### Probabilistic study

- One stroke : flat histogram
- Maximum: low values become less probable

Stroke1      Stroke2      Histogram of stroke 1 (or 2)

Max of stroke 1&2      Overlap (in blue)

Stroke - Equilibration - Decoupling - Results 26

### Probabilistic study

- One stroke : flat histogram
- Maximum: low values become less probable
- We did the math: Histogram must become linear

Stroke1      Stroke2      Histogram of stroke 1 (or 2)

Max of stroke 1&2      Overlap (in blue)      *What math says*

Stroke - Equilibration - Decoupling - Results 27

### Probabilistic study

- One stroke : flat histogram
- Maximum: low values become less probable
- Histogram becomes linear

Stroke1      Stroke2      Histogram of stroke 1 (or 2)

Max of stroke 1&2      Overlap (in blue)      Histogram of overlap

Stroke - Equilibration - Decoupling - Results 28

### Probabilistic study

- And we even did the math for N strokes!
- N strokes :  $X^{N-1}$

Max of stroke 1&2      Overlap (in blue)      Histogram of overlap

Max of stroke 1,2&3      Overlap (in black)      Histogram of overlap

Stroke - Equilibration - Decoupling - Results 29

### Equilibration

- Render a coverage map (# strokes/pixel)

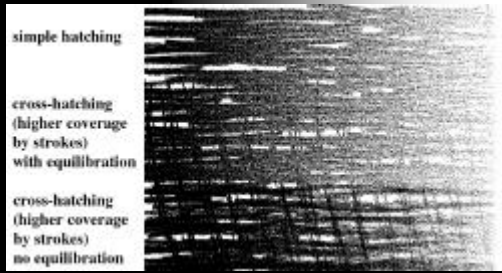
```

    graph LR
      A[strokes] --> B[threshold map]
      A --> C[coverage-map]
      B --> C
      C --> D[equilibration]
      D --> E[equilibrated threshold map]
  
```

Stroke - Equilibration - Decoupling - Results 30

## Results of equilibration

- Gradient target tone



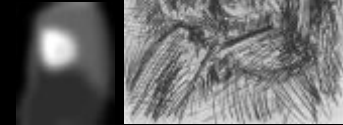
## Plan

- Stroke model
- Rapid equilibration
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- Implementation & results

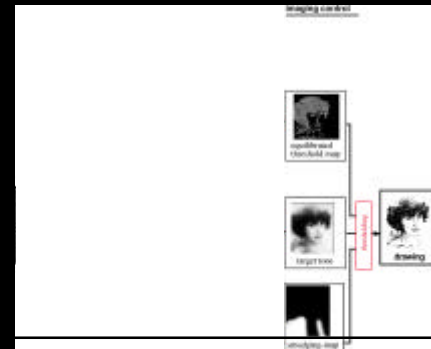


## Precision

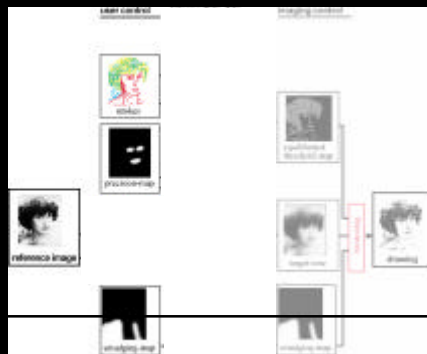
- Stroke saliency vs. tone precision
  - Vary the degree of equilibration
- Spatial detail
  - Spatially varying Gaussian blur for target tone



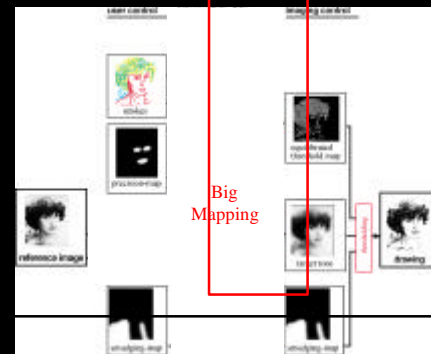
## Imaging control-space



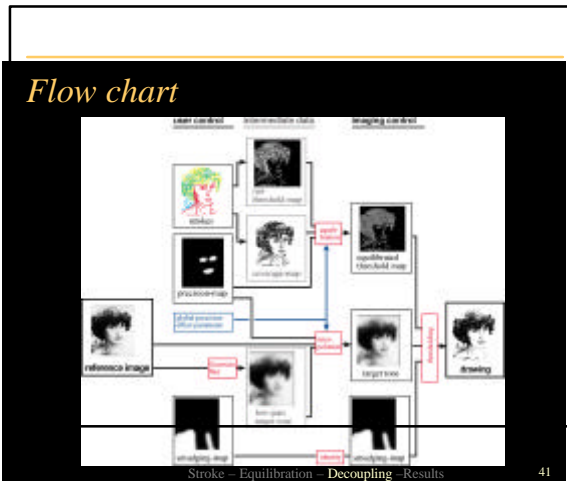
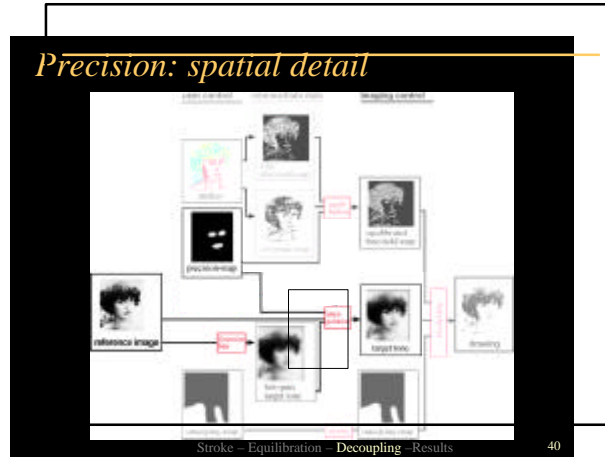
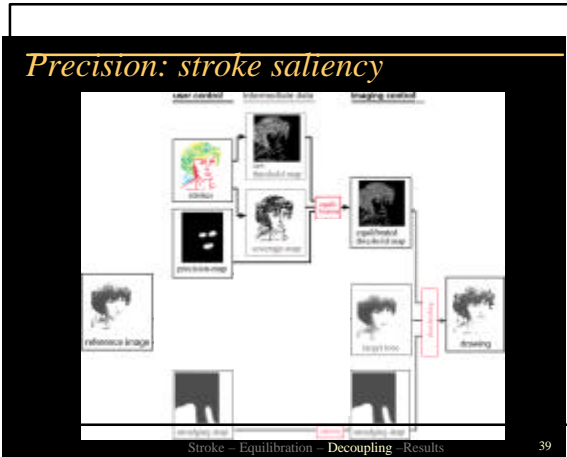
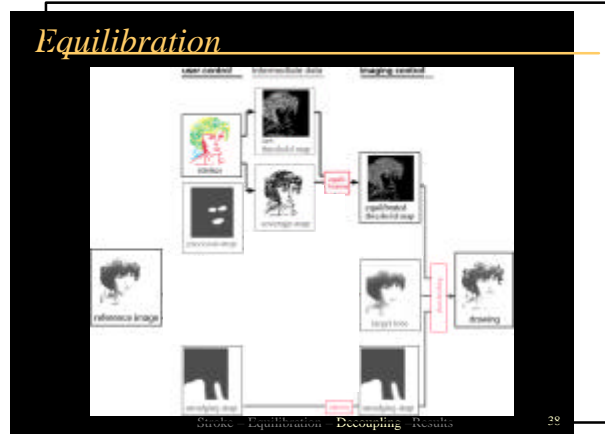
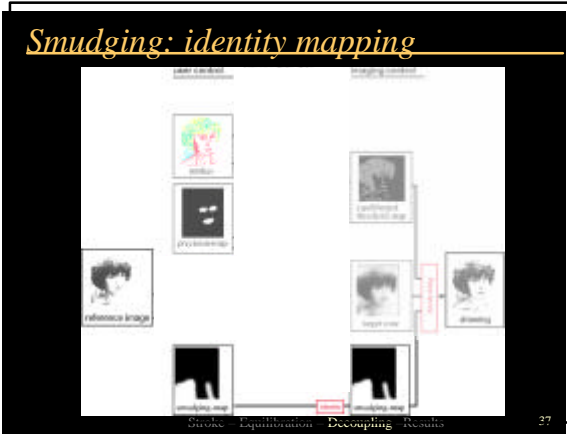
## User control-space



## Image generation as a mapping







### Plan

- Stroke model
- Rapid equilibration
- High-level decoupling
- Implementation & results

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## Video

- Recorder on an SGI Octane2

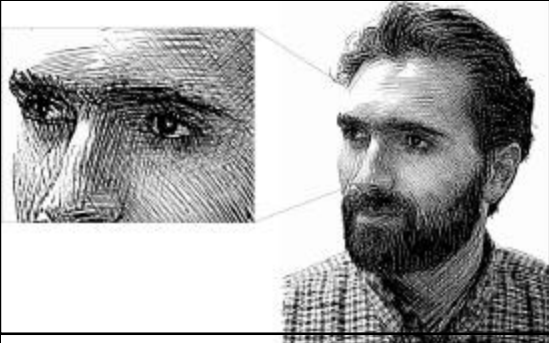
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## Charcoal



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## Etching



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## Engraving



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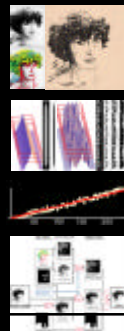
## Red chalk



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## Conclusions

- Interactive traditional drawing
- Thresholding stroke model
- Probabilistic equilibration
- High level control



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### *Future work*

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- High level texture
- Elaborate hatching
- Color
- Non-photorealistic perspective
- 3D
  
- Style
- NPR Inter-operability through modules & specs.

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