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# Understanding and Optimising Screeners

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# Phil Collins

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- Engineer and mathematician
- Director – Advanced R&D
- 30+ years experience in printing and pre-press
- Interests: cycling, sailing, wine, screening

# Summary

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- Why you should care about screeners
- What screeners are available
- Which factors affect screener quality
- How fast different screeners run
- Choosing screeners for your digital print system

# Screening - Overview and History

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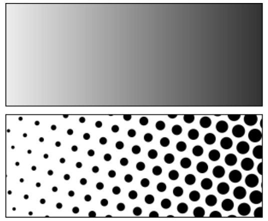
- ‘Screening’ or ‘halftone screening’ is the process of turning a continuous tone (‘contone’) image into an image that a printer can use. It creates patterns of dots which approximate shades of grey.



Contone to Halftone

- At its most basic, a screen is a form of stencil. It prevents ink from reaching the surface in some areas but allows it in others. A screen divides the tonal range into two, hence ‘halftone’.

Stencil output

- Printers quickly wanted to be able to print shades of colours and so the process of halftone screening was devised using ‘photographic screens or veils’ by William Fox Talbot in around 1850

William Henry Fox Talbot, by John Moffat, 1864.

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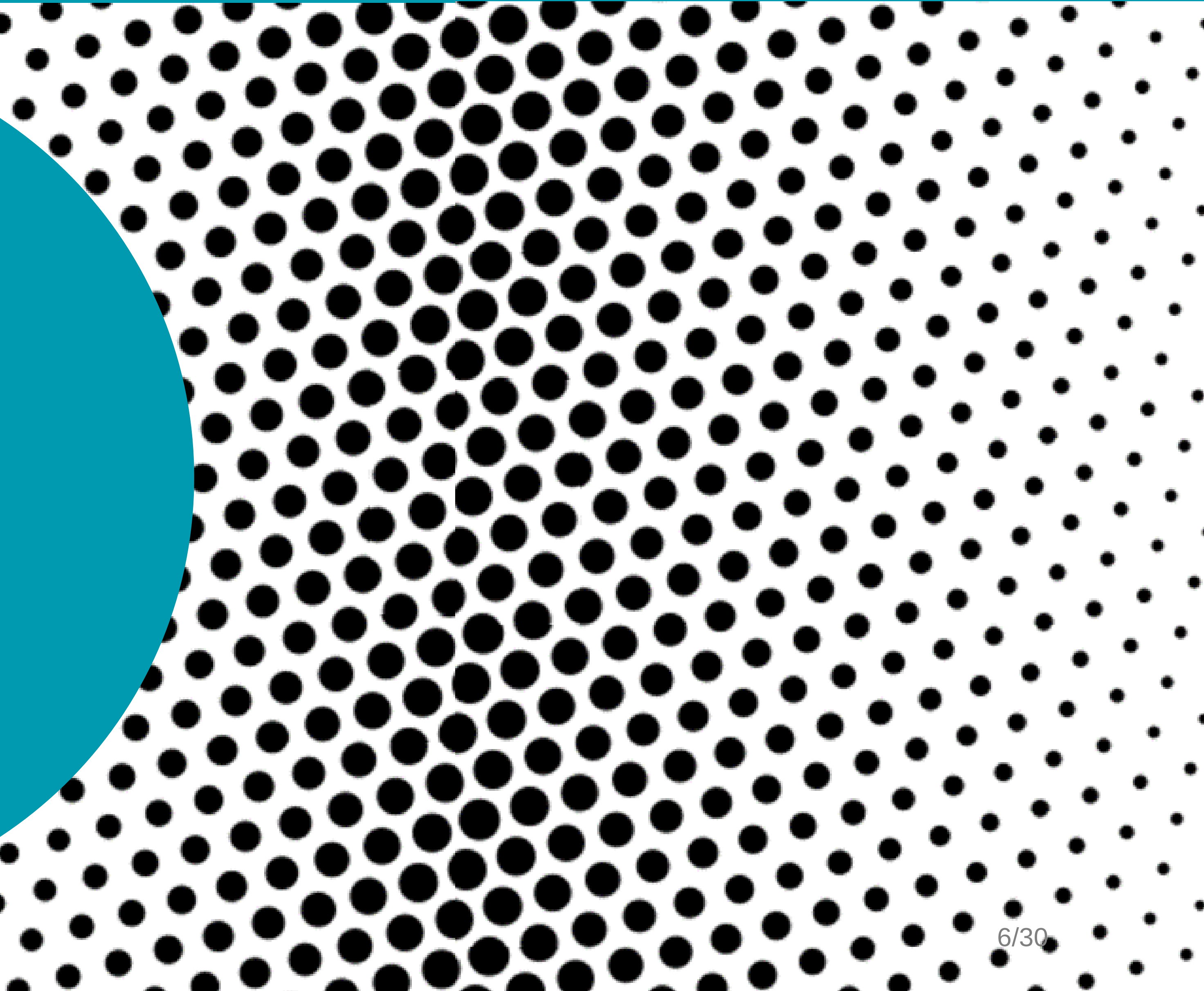
# Amplitude Modulated Screening

- Amplitude Modulated was the dominant form of screening for most of the C20th
- It was implemented by photographic methods which integrated well with other pre-digital print processes
- The main variation was Lines Per Inch, but some shape variation was available
- Screen patterns were the same for each channel, but rotated for different colours
- Early digital screeners concentrated on emulating these capabilities



# Frequency Modulated Screening

- Frequency Modulation keeps the dots the same size, but varies the distance between them
- Not easy with photographic screens, but simple with digital
- Result is a much smoother greyscale
- Requires good dot gain control, hence more difficult to use with offset presses

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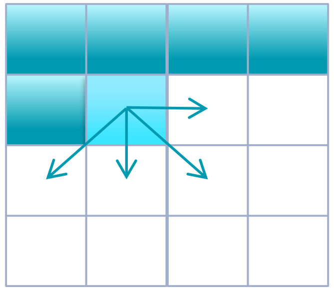
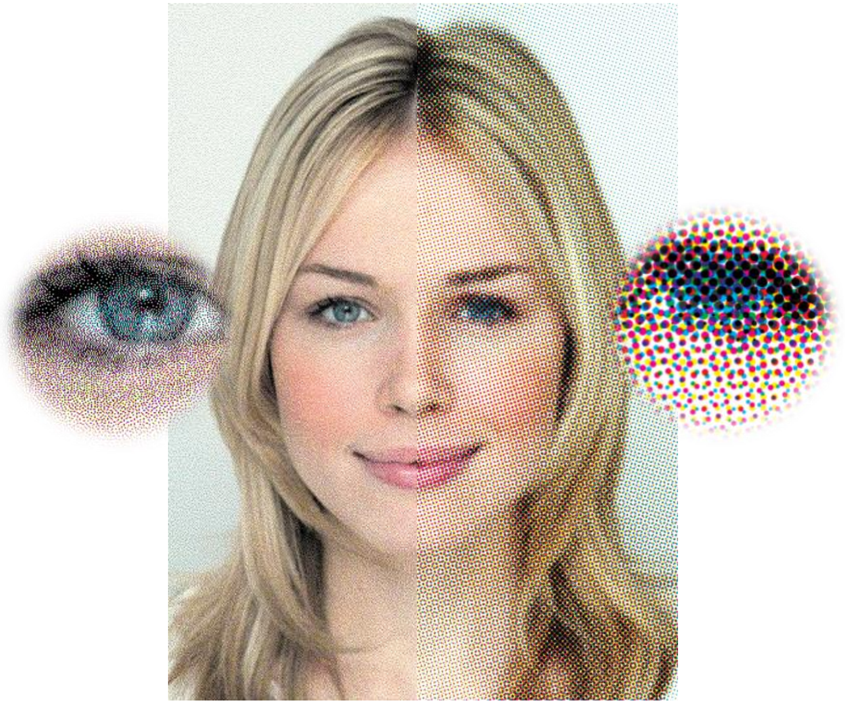
# Frequency Modulated vs Amplitude Modulated

- Frequency Modulated (FM) screening is an alternative to Amplitude Modulated (AM)
- Also referred to as Stochastic Screening
- Popular implementations are Error Diffusion (ED) or Ordered Dither (OD)
- Often combined when using grey-level printheads as a FM/AM hybrid



$$\begin{bmatrix} & & * & \frac{7}{16} & \cdots \\ \cdots & \frac{3}{16} & \frac{5}{16} & \frac{1}{16} & \cdots \end{bmatrix}$$

Robert Floyd and Louis Steinberg published this algorithm in 1976 in a technical paper titled '*An adaptive algorithm for spatial grey scale.*'



Frequency Modulated (Floyd Steinberg)

Amplitude Modulated

# Ordered Dither

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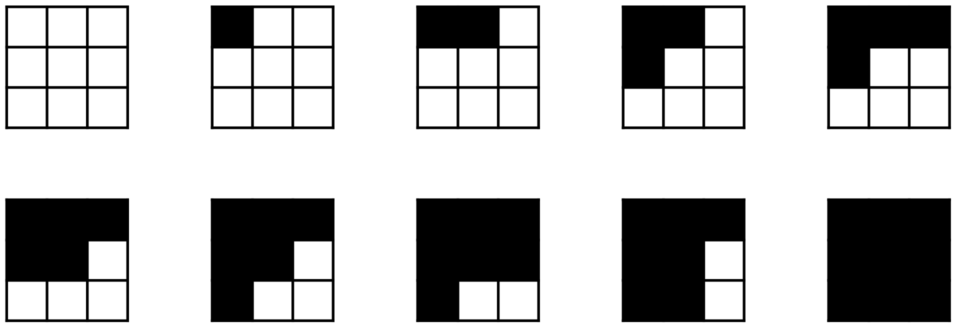
- Ordered Dither divides the image into fixed size cells, and turns on pixels in each cell according to the contone value
- Unlike Error Diffusion it doesn't recalculate the error for each pixel, but still approximates the contone value across the cell
- For each pixel it's just a simple comparison,  so it's also called 'Threshold Screening'



3x3 cell example: only 10 grey levels

| | | |
|---|---|---|
| 12 | 10 | 21 |
| 18 | 78 | 86 |
| 28 | 84 | 67 |

Contone – Average 44.9%

| | | |
|---|---|---|
| 10 | 20 | 30 |
| 40 | 50 | 60 |
| 70 | 80 | 90 |

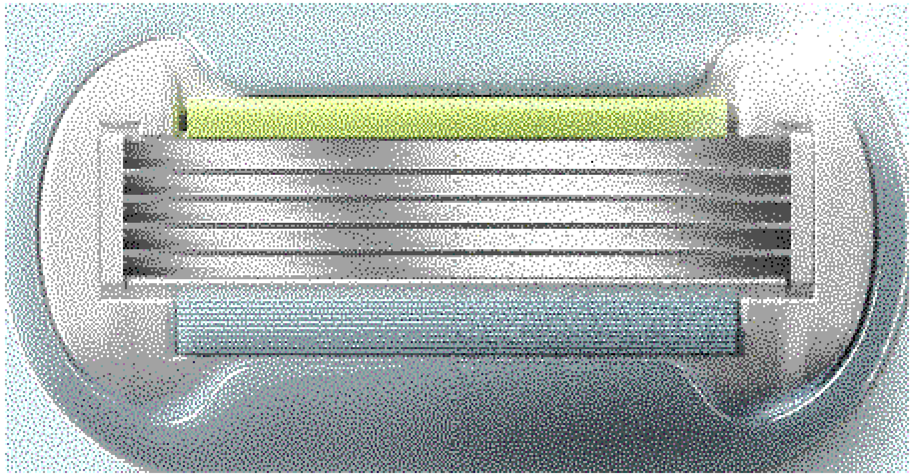
Threshold Cell

| | | |
|---|---|---|
| 100 | 0 | 0 |
| 0 | 100 | 100 |
| 0 | 100 | 0 |

Output – Average 44.4%

# ED vs OD: Quality Comparison

- Comparison is difficult without controlled viewing conditions
- But side-by-side ED shows slightly less grain in skin tones and better fine detail
- Differences become smaller at higher resolution



Error Diffusion Ordered Dither

Error Diffusion Ordered Dither

# Optimising Screener Quality

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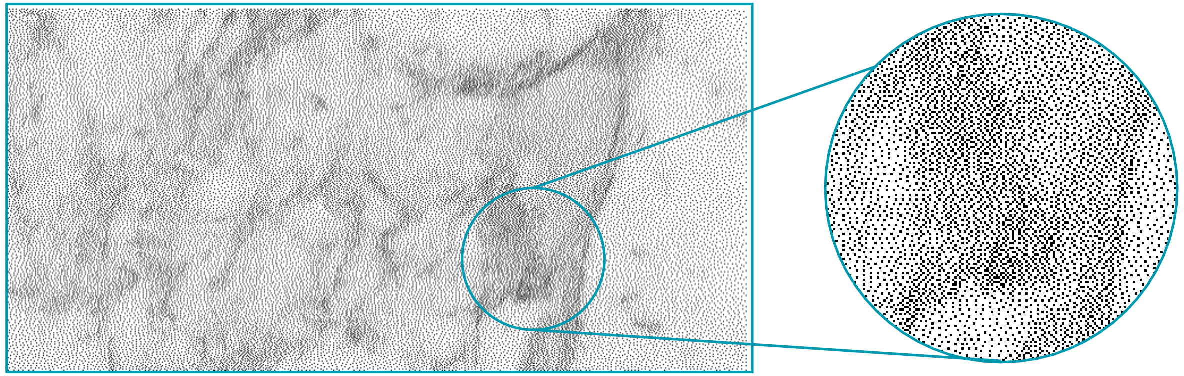
## Some issues are inherent to the process of screening

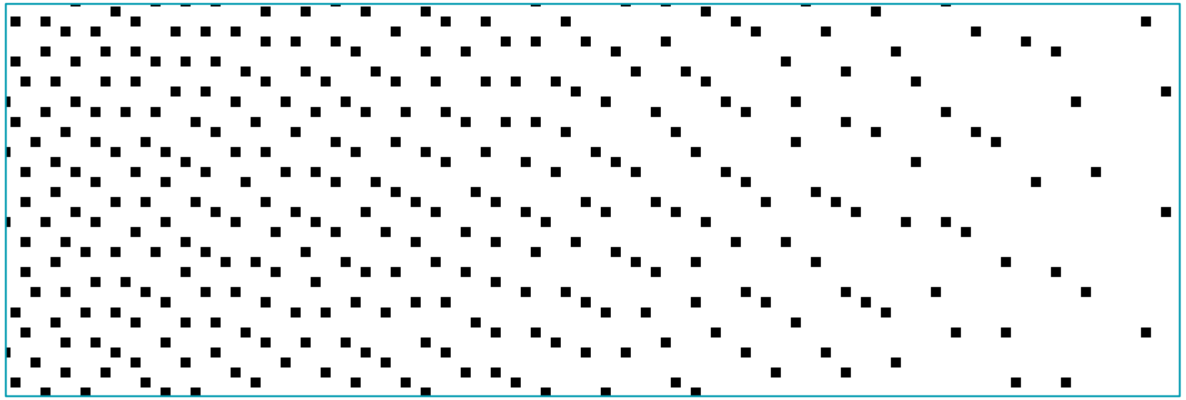
### Match ink density to image ranges to avoid grain

- Inks with high optical density will result in grainy textures in low density areas
- Use small drop sizes or light inks to reduce dot spacing



### Tune algorithms to avoid artefacts

- Human visual cortex is very sensitive to patterns
- Error Diffusion is usually tweaked by:
    - Bi-directional or serpentine scanning
    - Damping errors by a few %
    - Adding a small amount of noise

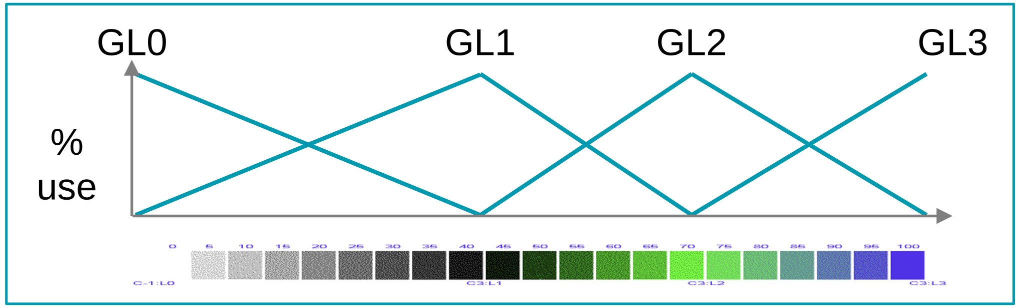


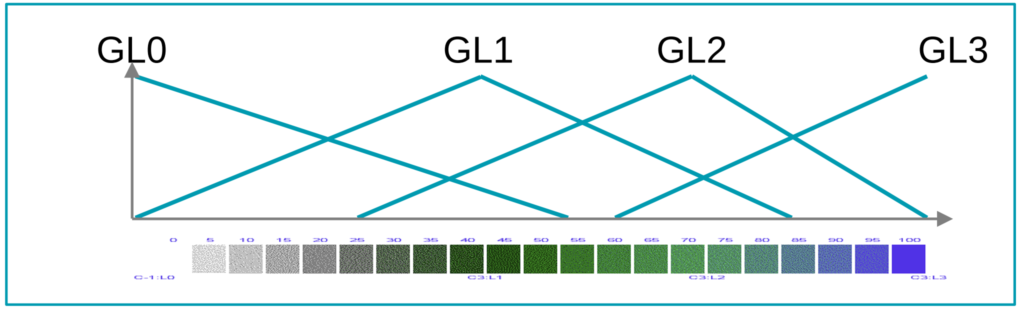
# Optimising Screener Quality

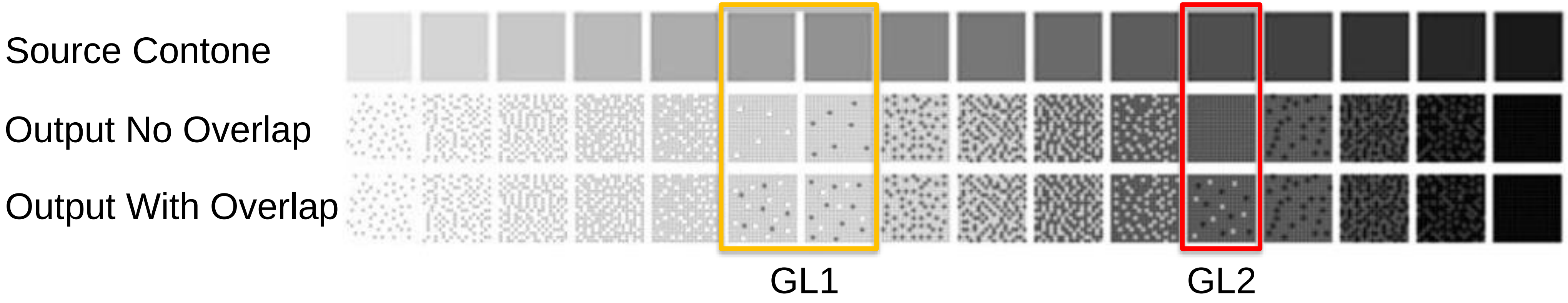
## Another inherent issue is greyscale texture

### Avoid areas of single drop sizes in greyscale

- Human visual cortex is also sensitive to texture
- Greyscale screeners should avoid areas with single drop sizes because they create a change of texture
- This Is achieved by mixing in other drop sizes, known as grey level overlap.



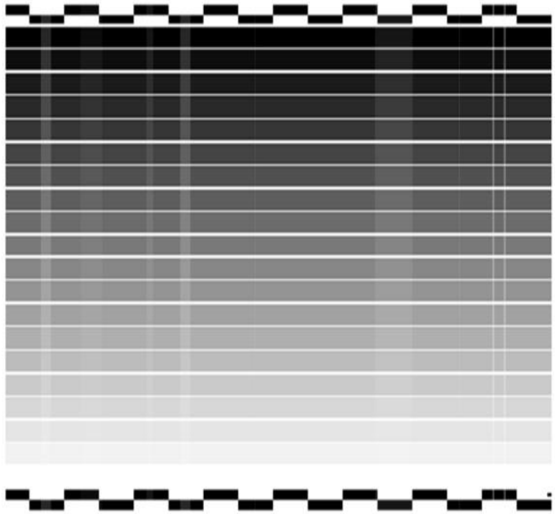



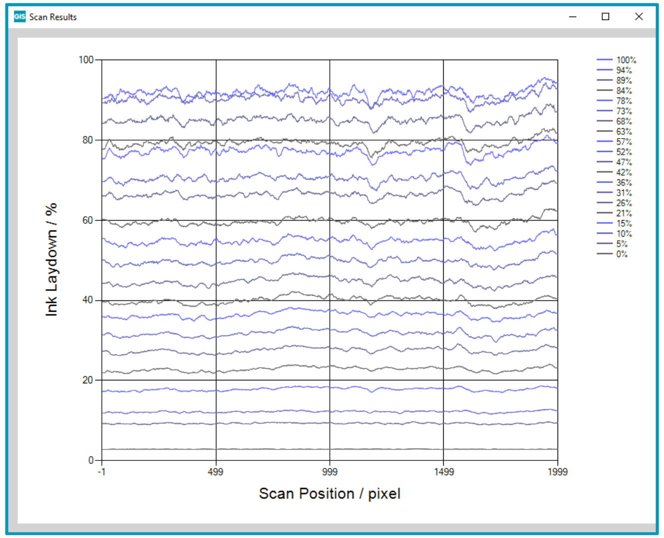
# Optimising Screener Quality

## Other problems are linked to imperfections in the print system

### Calibrate for printhead and nozzle variations

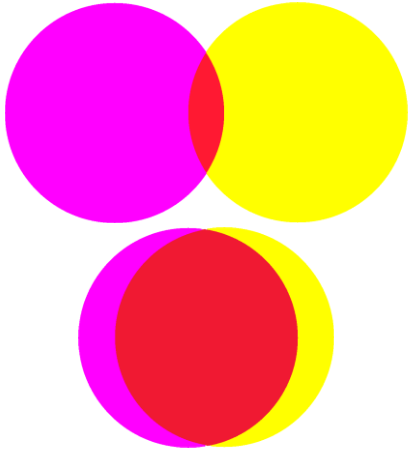
- The precise jetting performance varies between nozzles and between printheads – visible as density shifts
- Screeners can be calibrated to compensate so the resulting output does not show the density shifts

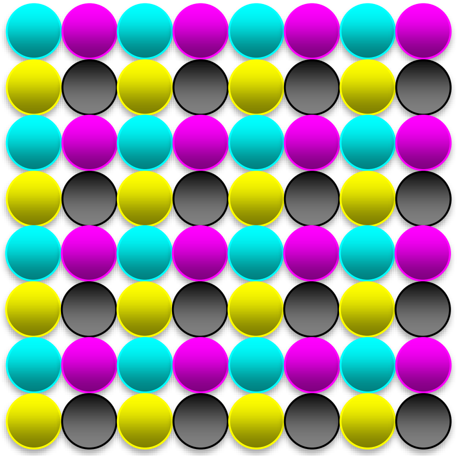





### Match screener choice to mechanical stability

- Ensuring mechanical stability in spite of variations in temperature, vibration and wear is expensive
- Density and colour shifts can be avoided by biasing the screener to reduce overlaps in mid-tones
- This is a trade-off between stability and either colour gamut or fine detail

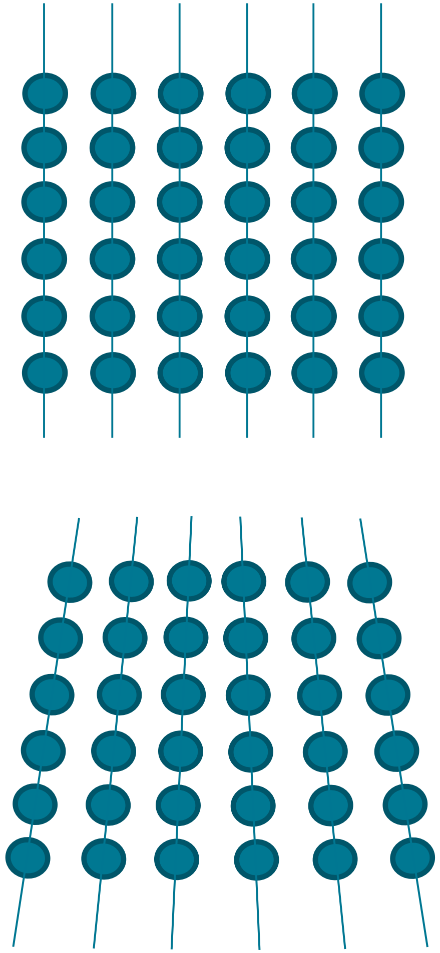


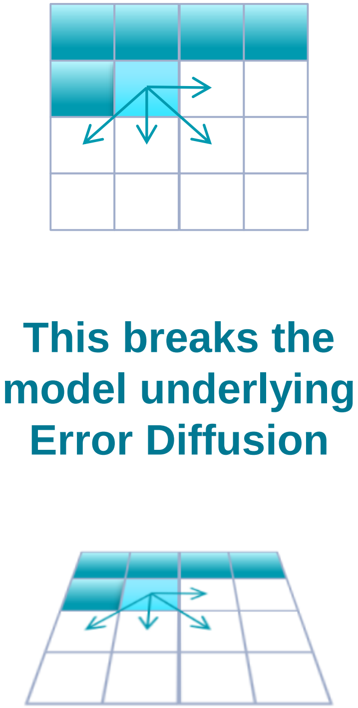


# Other Challenges for Screener Quality

Curved surfaces undermine the assumption in most screeners that dots are regularly spaced on a grid

CMYK 1200dpi on a sphere of radius 75mm

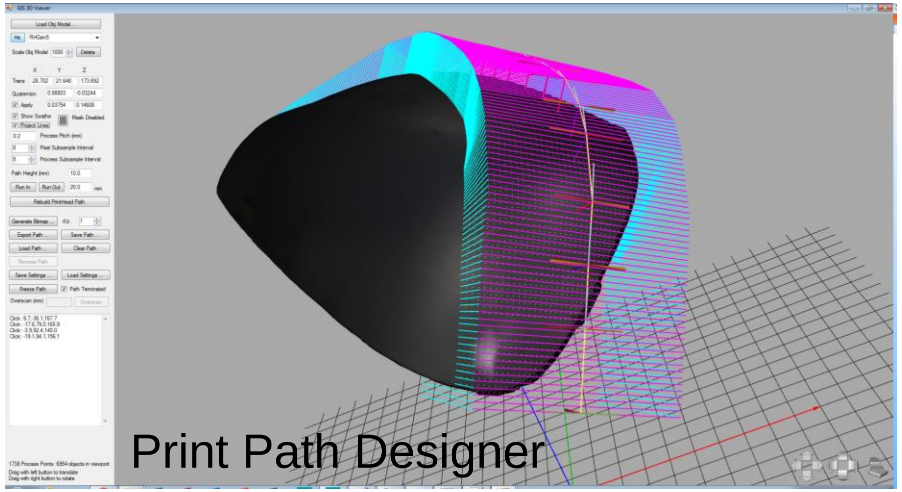




**This breaks the model underlying Error Diffusion**

# Direct To Shape

- Real life products are often not flat, but have complex curved surfaces, as in the case of this wing mirror
- Screeners for use on such surfaces have to adapt to the changing geometry as the printhead moves across the surface under robot control




Motion Control

Print Data

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# ED Performance

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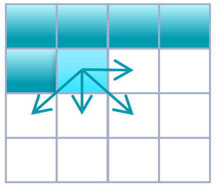
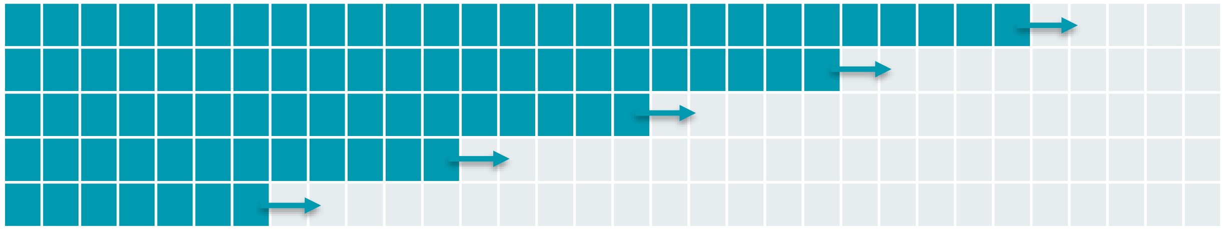
## Many ingenious ideas have been proposed for accelerating Error Diffusion



- They all seem to have some drawbacks
- Here are a couple of examples

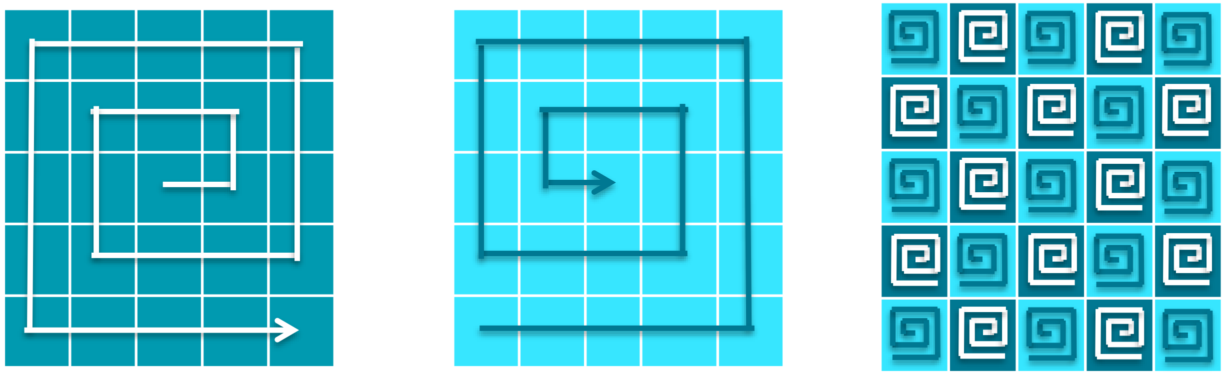
## Echelon

- Much more complex than single thread
- Doesn't support serpentine
- Larger algorithm, harder to optimise



## Spiral / Pinwheel

- Even more complex to implement
- Difficult to understand artefacts at corners
- Requires GPU or similar parallel hardware
- Claimed performance is similar to CPU



## Conclusion

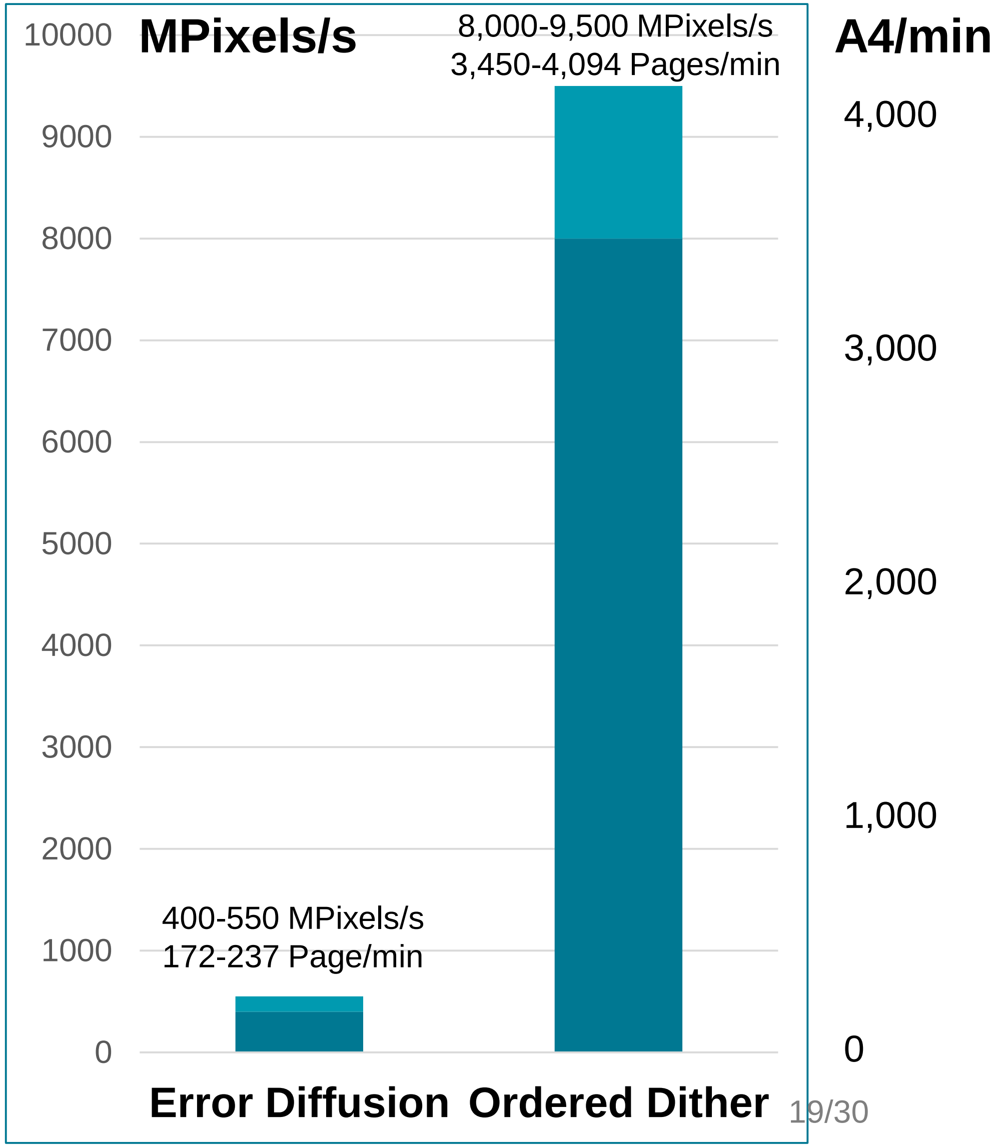
- Floyd-Steinberg and other ED algorithms can be optimized as tight loops on general purpose CPUs
- For most print systems, parallel processing is most effectively implemented across multiple channels and pages

# ED vs OD: Performance

- Ordered Dither is significantly faster than Error Diffusion
- We measure throughput performance in millions of pixels per second. It may be easier to visualise in pages per minute
- These numbers are just for a single core

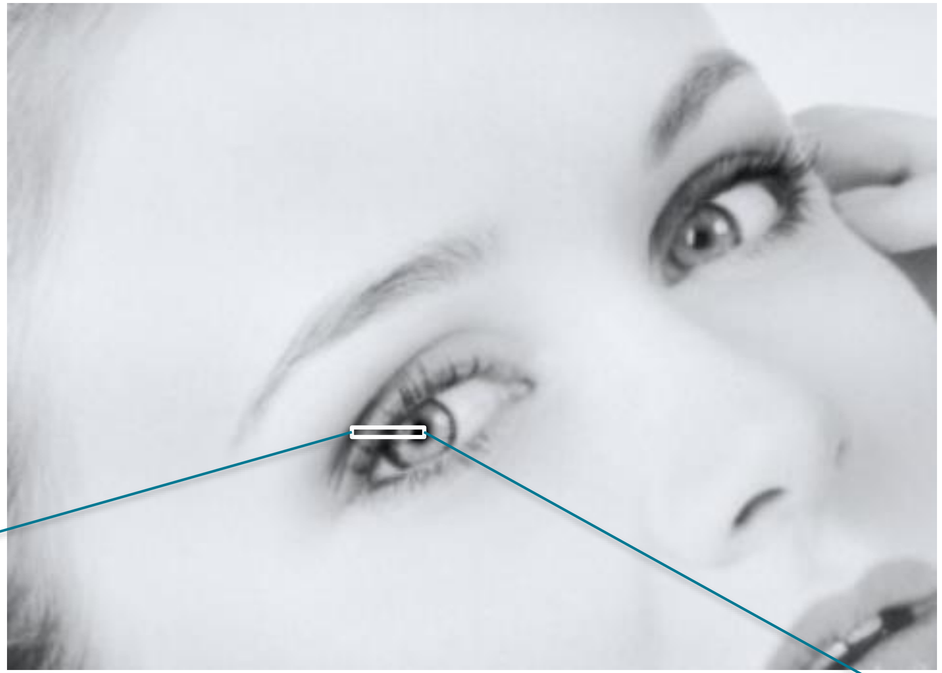
We always screen the whole image including any white space

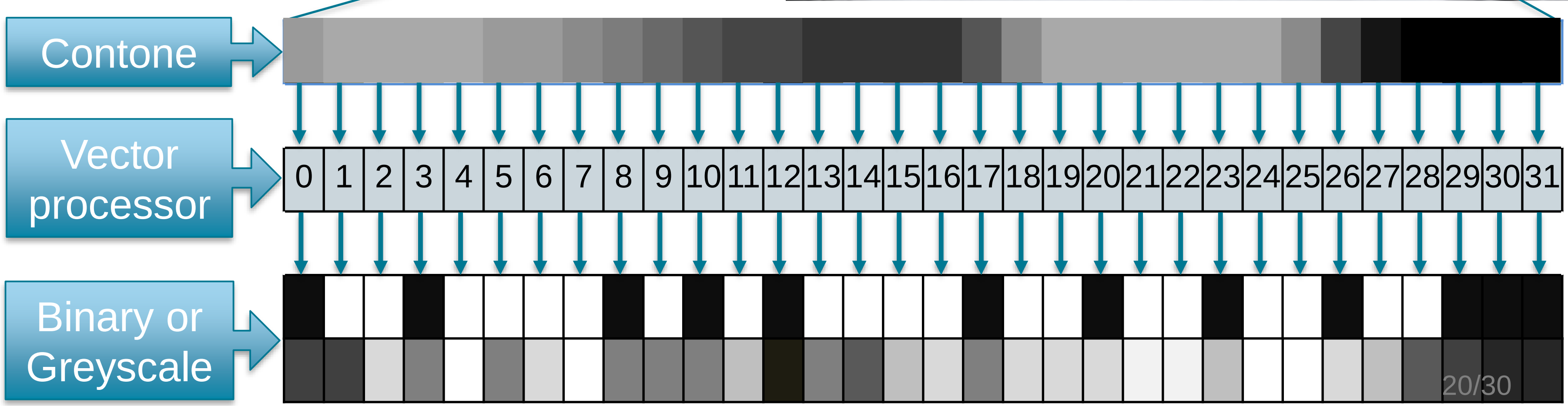
Performance measured on various Intel i7 Core processors, 2013 onwards.



# OD Performance

- The Ordered Dither algorithm can be executed in parallel on vector processors
- x64 processors have offered vector capability as standard since 2013
- Can process 32 or even 64 pixels at once





# More OD Performance

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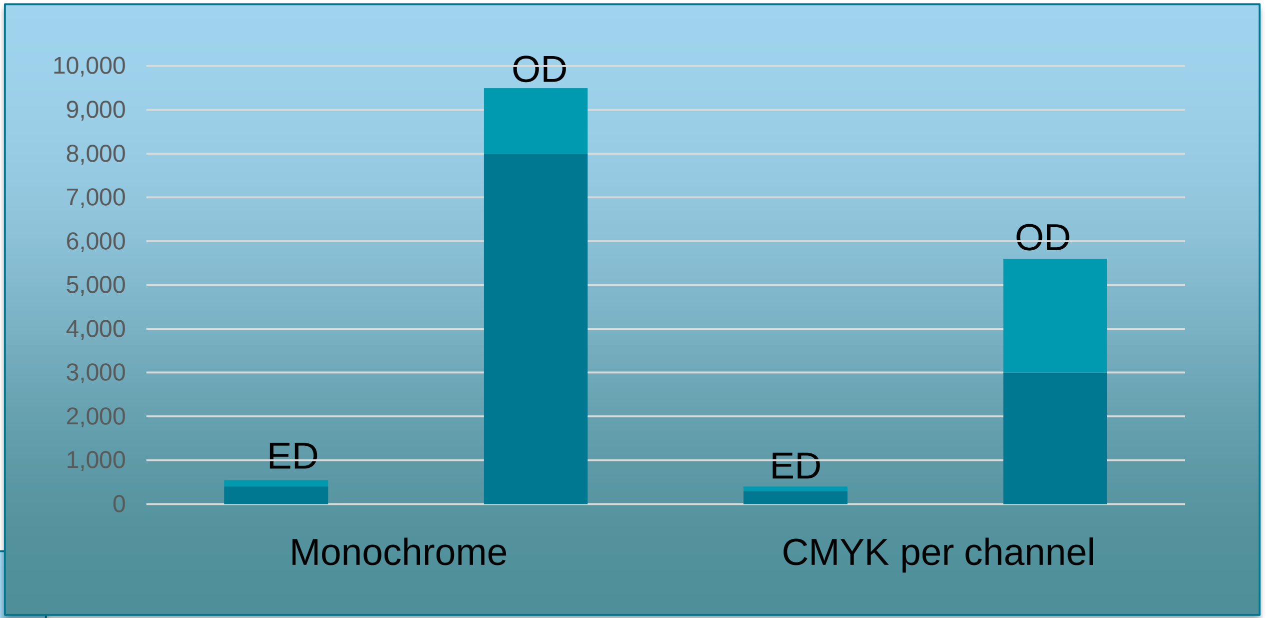
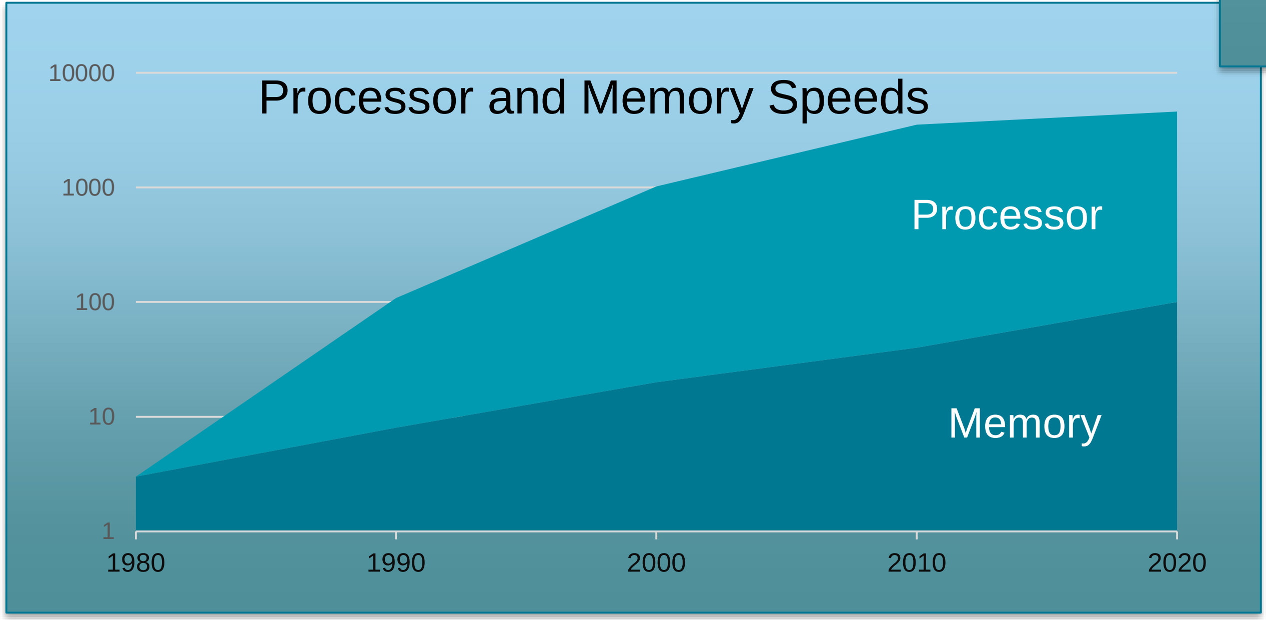
- Not only is single core performance comparison impressive
- But multi-channel throughput is now limited by cache and memory bandwidth rather than processor clock speed
- And this is addressed in newer processor models

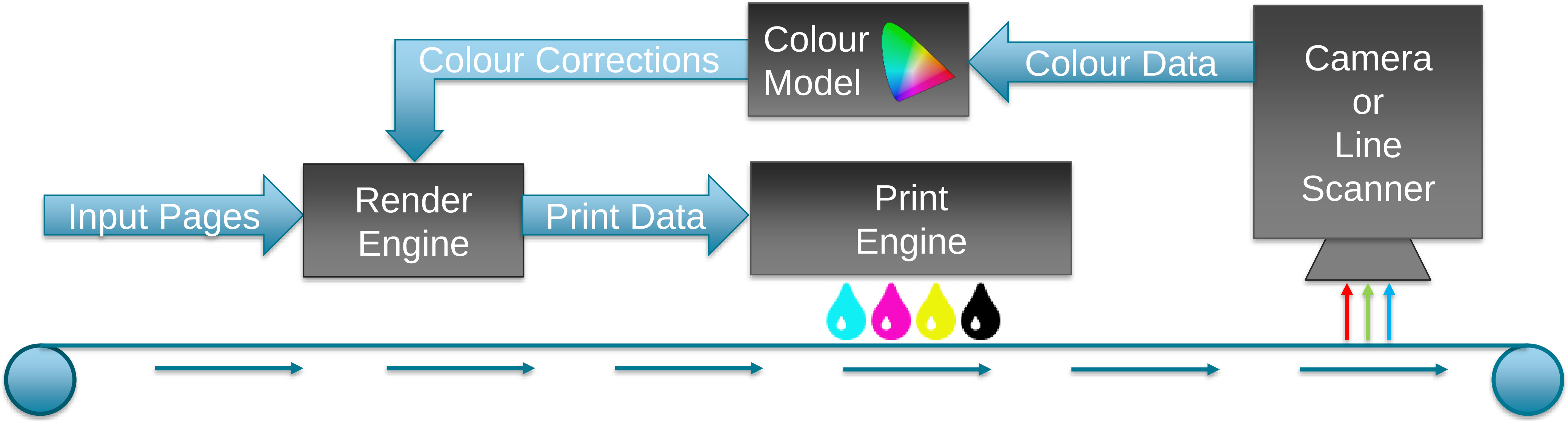



- Processor clock speeds have almost stopped increasing over the last 10 years
- Manufacturers are concentrating on delivering performance in other ways
  - 10x more cores in the last 10 years
  - Integrated vector processors
- These benefit OD rather than ED screeners

# Closing The Loop

- Closed loop feedback is another reason why screener performance may be important
- Responding to changes in the print system in real-time reduces system downtime and wasted materials
- A change in the colour model will require re-screening



# A Real World Application

- In the real world, screening will typically be part of a mixed workload
- The video shows an A4 brochure, rich with photographs, printing at 100 metres/minute
- All the print data is produced in real-time from PDF, colour managed, and screened on the fly

Industrial Inkjet PrintEngine with Konica Minolta KM1800i printheads Powered by GIS datapath

Courtesy of Industrial Inkjet Ltd

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# Performance Requirements

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## Throughput

- How many pages or metres of output per minute?
- How many colours / channels?

## Latency

- How soon is the input available before it must be printed?

## Static or Variable

- Does some or all of the content vary on each print?

# Quality Requirements

## Resolution

- What is the pixel resolution in the process and cross-process directions?
- How many bits per pixel?

## Robustness to print imperfections

- Is it required to print light areas with dark inks?
- What drop sizes are available?

## Robustness to drop placement errors

- What is the mechanical accuracy of the system?

# Integration Examples

| Print Configuration | Screener Considerations |
|---|---|
| Static pre-RIP'ed | Screen once for best quality. Screener speed usually not important. |
| Single-pass low latency | Screener speed dominates, favouring Ordered Dither. |
| Hybrid AM/FM | Drop size selection. Grey level overlap. |
| Scanning-XY with density correction | Mechanical stability. Robustness to density / colour shifts. |
| Direct to Shape with robot transport | Curved surface awareness. Integration with motion control. |
| Closed Loop | Screener speed must match changing inputs. |

# The GIS EcoSystem

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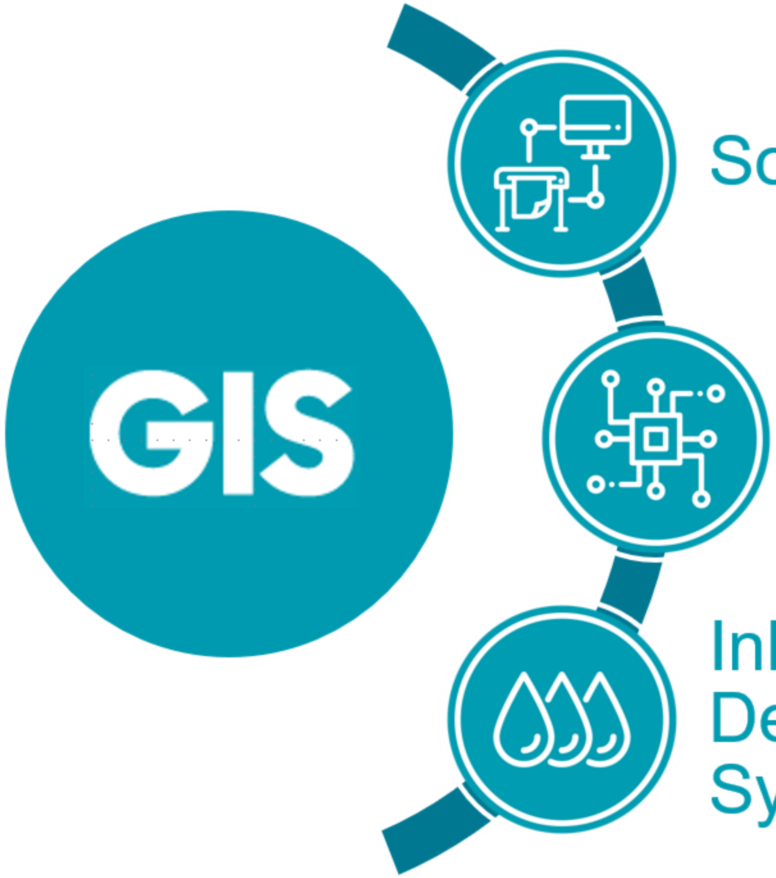
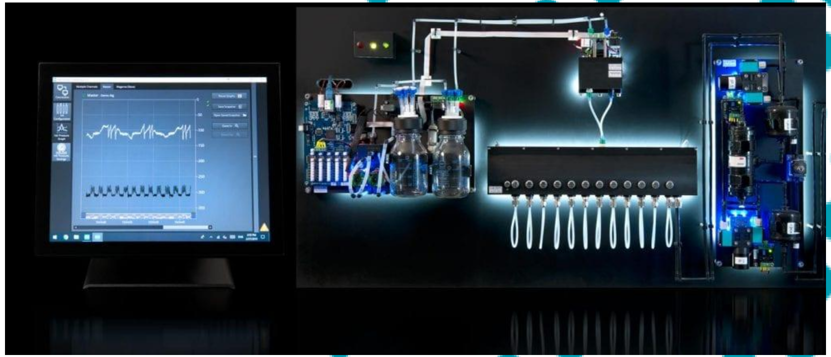
## Complete image management from pixel to drop




Software

Datapath Electronics

Ink Delivery Systems

# Conclusions

- Screeners are essential in almost all print systems
- They were a significant performance limit, but progress has taken us well beyond that
- With care, your screener can help handle imperfections in other parts of the system

# Any Questions?

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