3D scene illusion via autostereograms

Marie Lecroël & Pierre-Louis Barbarant

November 15, 2022

Sciences Sorbonne Université

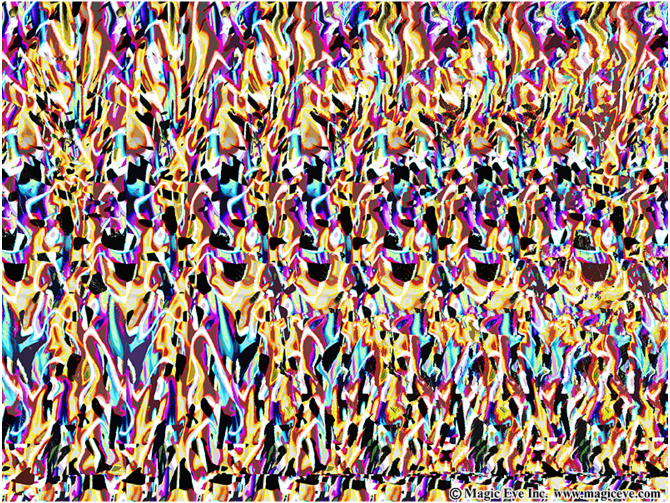


Figure 1 – An example from the famous *Magic Eye* book series

Outline of the presentation

- What are stereograms ?
- Short history of random dots stereograms
- The viewing principles
- Autostereograms generation
- 3D shape reconstruction from autostereograms

Stereograms = stereoscopic images :
Images using stereopsis from binocular vision to produce an illusion of depth.

Usually, "stereogram" refers to a pair of images, one to be seen by the left eye, one to be seen by the right eye, to simulate the dissimilarity between the two monocular images when looking at a 3D object.

Figure 2 – View of Boston, by John P. Soule, 1860

3D scene illusion since the 19^{th}

- 1838 : first explanation of stereopsis and invention of the first stereoscope by Charles Wheatstone [Whe38]
- second half of the 19^{th} century : popularisation of the stereograms
- 1960 : Random Dot Stereograms (RDS)
- 1990 : autostereograms

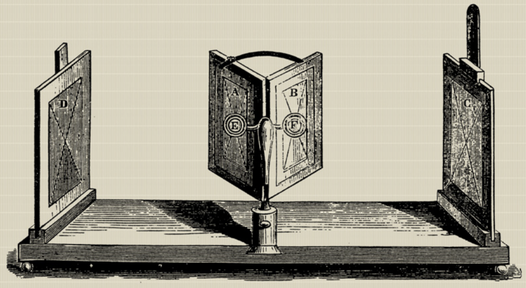


Figure 3 – The first stereoscope - *figure taken from Wheatstone (1838)*[Whe38]

1960 : Binocular Depth Perception of Computer-Generated Patterns [Jul60]

Random dot stereograms were invented by Bela Julesz as a way to study stereopsis in human vision : deprive the observer of all depth clues except stereopsis to force their brain to estimate depth by computing horizontal disparities.

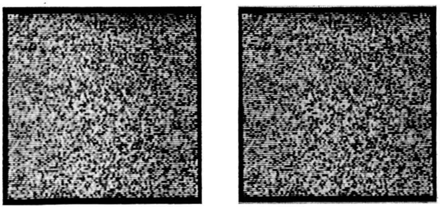
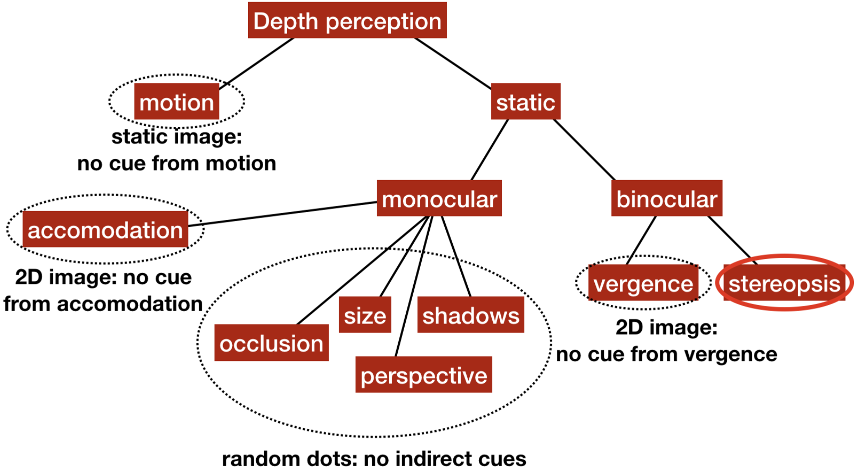


Fig. 4 — Stereo pair with center square above the background.

Figure 4 – The first RDS - *figure taken from Julesz (1960)*[Jul60]


Depth perception
motion
static image:
no cue from motion
static
monocular
binocular
accomodation
2D image: no cue
from accomodation
size
shadows
occlusion
perspective
random dots: no indirect cues
vergence
stereopsis
2D image:
no cue from vergence

1990 : The Autostereogram [TC90]

Christopher Tyler and Maureen Clarke proposed a variant : autostereograms, also known as SIRDS (Single Image RDS), as a way to visualize 3D scenes without special tools (lenses, special screens, glasses...)

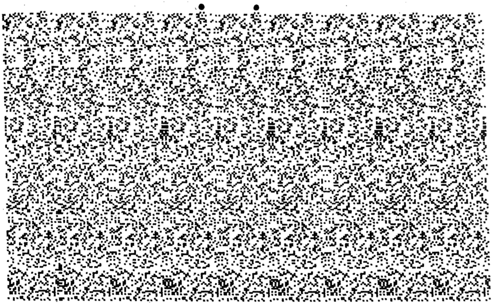


Figure 1. Autostereogram of a checkerboard in depth. Cross the eyes slightly so that the two solid fixation dots appear as three dots in a line. Focus on the center one until depth is perceived in the rest of the display.

Figure 5 – The first SIRDS - *figure taken from Tyler and Clarke (1990)*[TC90]

Viewing techniques

Idea : to simulate the depth, make each eye see a slightly different pattern, with parts at different depths having undergone a different horizontal shift.

In autostereograms, there is only one image, and no apparatus : the observer has to change the vengeance of its eyes, so that each of them focus on a different part of the image.

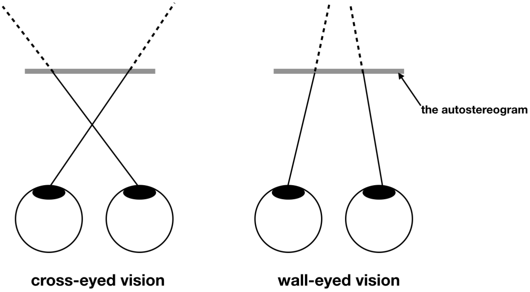


Figure 6 – The two viewing techniques

Generating an autostereogram

Ron Kimmel ([Kim02]) proposes an easy algorithm to generate a square-shaped random-dot autostereogram :

Algorithm 1 Autostereogram generator

Input: Z : depth map, M : width and height of Z, N : maximum depth, R : pattern of size $N \times M$

Output: $M \times M$ autostereogram I

for j in 1...M **do**
    for i in 1...M **do**
        if $i < N$ **then**
            $I(i,j) = R(i,j)$
        else
            $I(i,j) = I(i - N + Z(i,j), j)$
        end if
    end for
end for
return I

R. Kimmel's examples

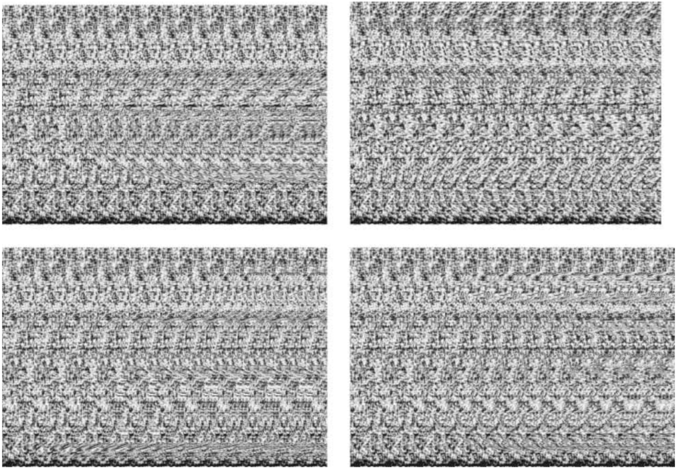


FIG. 3. Random dot autostereograms.

Figure 7 – Four autostereograms generated by R. Kimmel in [Kim02]

Our examples (1/4)

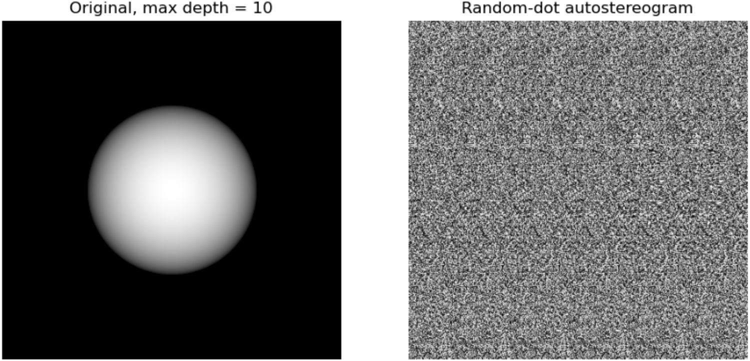


Figure 8 – An example on a sphere $M = 400, N = 70$

Our examples (2/4)

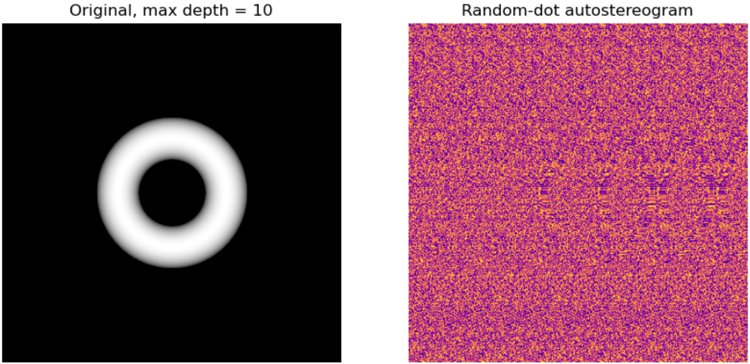


Figure 9 – An example on a torus $M = 400, N = 70$

Our examples (3/4)

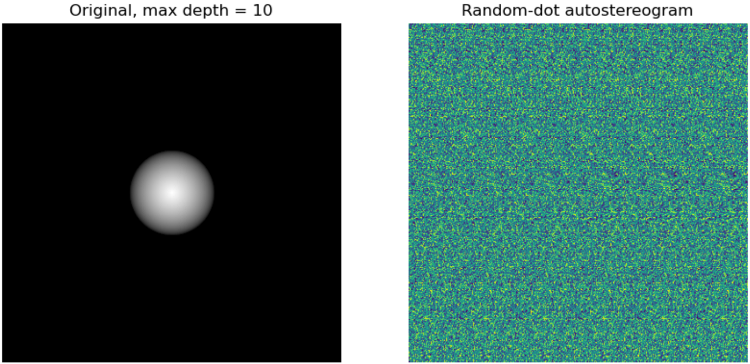


Figure 10 – An example on a cone $M = 400$, $N = 70$

Our examples (4/4)

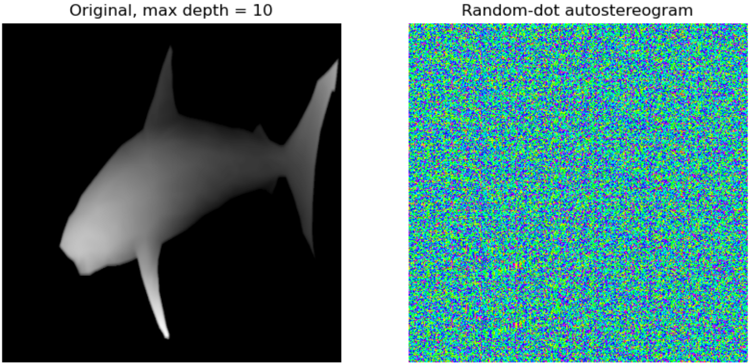


Figure 11 – An example on the shark image (resized from Wikipedia)
$M = 400$, $N = 70$

3D scene reconstruction

Theorem 1 (Exact reconstruction).
If $\forall i \neq k,\ R(i,j) \neq R(i-k,j)$ *then* $\exists! k \in \{1 ... N\}\ I(i,j) = I(i-k,j)$

$\Longrightarrow$ In other terms, when the pattern does not exhibit repeating colors among each line, it is possible to exactly reconstruct the depth map.

An algorithm for exact reconstruction [Kim02]

Algorithm 2 Exact reconstruction of the depth map Z

Input: I : autostreogram, M : width and height of Z, N : maximum depth, R : pattern of size $N \times M$

Output: $M \times M$ depth map Z

for j in 1...M-1 **do**
    for i in N...M-1 **do**
        find the unique $k_{ij} \in \{1, ..., N-1\}$ such that $I(i,j) = I(i-k_{ij}, j)$
        $Z(i,j) = N - k_{ij}$
    end for
end for
return Z

In the general case

When the pattern R shows repeating colors in a line, we may find multiple candidates of k for the value of $Z(i,j)$. In that case, we can select the first correlation which corresponds to the minimal $k > 0$ such that $I(i,j) = I(i-k,j)$. However the yielded result appears very noisy :

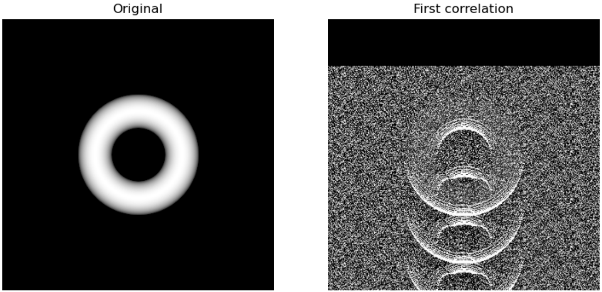


Figure 12 – Result of first correlation reconstruction on the torus

Minimal Surface Refinement (MSR)

In order to reduce noise, we make the additional assumption that the object is *smooth*. We then select for each $Z(i,j)$ the value that minimizes the 6-triangles area among all admissible candidates at each iteration :

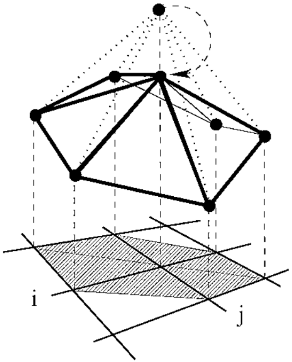


FIG. 2. The area of the six triangles is minimized by changing the $Z(i, j)$ candidate.

Figure 13 – Illustration from [Kim02]

Our examples (1/4)

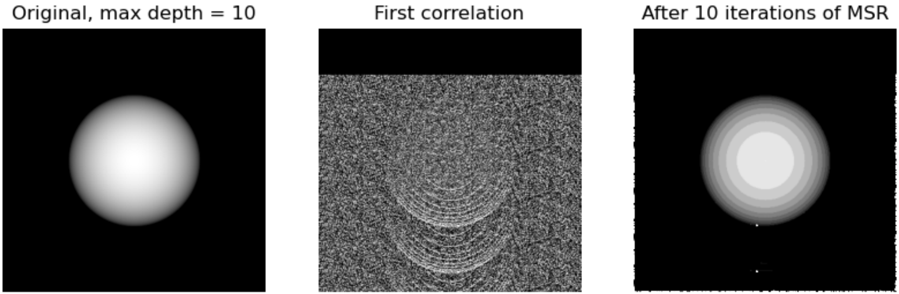


Figure 14 – An example of minimum surface refinement on a sphere

Our examples (2/4)

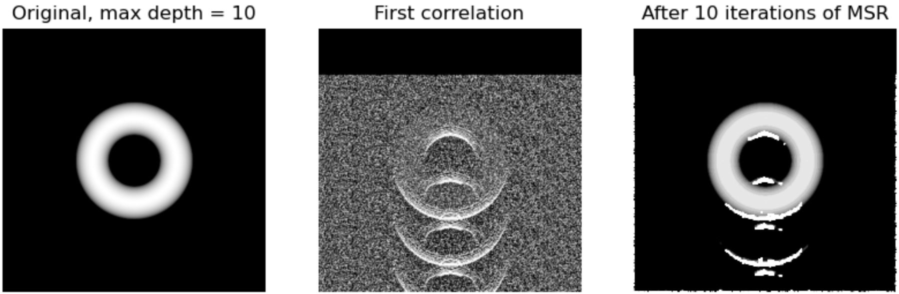


Figure 15 – An example of minimum surface refinement on a torus

Our examples (3/4)

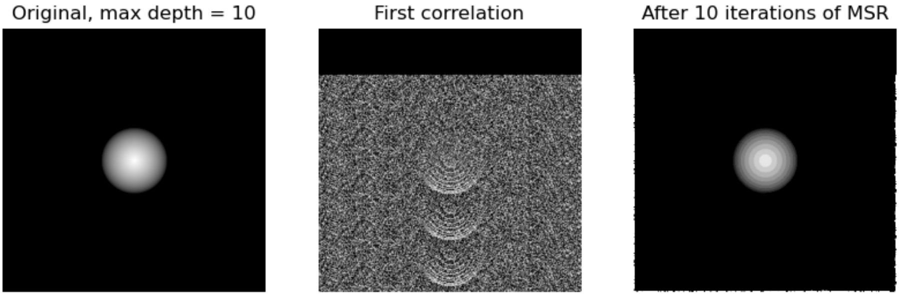


Figure 16 – An example of minimum surface refinement on a cone

Our examples (4/4)

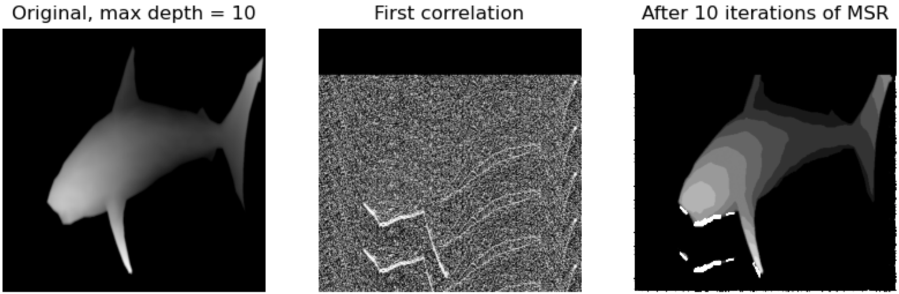


Figure 17 – An example of minimum surface refinement on the shark image

Conclusion

Random dot stereograms and autostereograms have provided excellent tools to study steeroscopy in human vision, and they have led to several important discoveries, like the Cyclopean paradigm.

They have also many obvious applications in the fields of art and computer-human interactions.

References

- Bela Julesz, *Binocular depth perception of computer-generated patterns*, The Bellsystem technical journal **39** (1960).
- Ron Kimmel, *3d shape reconstruction from autostereograms and stereo*, Journal of Visual Communication and Image Representation **13** (2002), no. 1-2, 324–333.
- Christopher W. Tyler and Maureen B. Clarke, *The autostereogram*, SPIE Proceedings **1256** (1990).
- Charles Wheatstone, *On some remarkable, and hitherto unobserved, phenomena of binocular vision*, The Royal Society (1838).

Any questions ?

All codes are available at
https://github.com/pbarbarant/VISION/tree/main/Autostereograms
Feel free to try and create your own autostereograms !