Motion Clouds: Model-based stimulus synthesis of natural-like random textures for the study of motion perception

Laurent U. Perrinet

Institut de Neurosciences de la Timone, CNRS / Aix-Marseille University, Marseille, France

March 22nd, 2012

Second BrainScaleS plenary Meeting - WP4

This work is supported by the European Union project Number FP7-269921, ``BrainScaleS''. Supplementary material can be accessed on the corresponding author's website at http://invibe.net/LaurentPerrinet/MotionClouds.

Motion Clouds: Model-based stimulus synthesis of natural-like random textures for the study of motion perception

Laurent U. Perrinet

Institut de Neurosciences de la Timone, CNRS / Aix-Marseille University, Marseille, France

March 22nd, 2012

Second BrainScaleS plenary Meeting - WP4

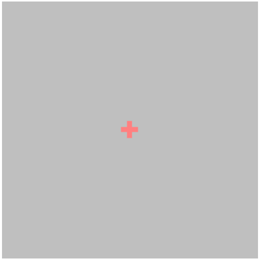
This work is supported by the European Union project Number FP7-269921, ``BrainScaleS". Supplementary material can be accessed on the corresponding author's website at http://invibe.net/LaurentPerrinet/MotionClouds.

(hello) Hi, I am Laurent U. Perrinet and I work at the team "inference in Vision & Behavior" supervised by Guillaume Masson in Marseille.

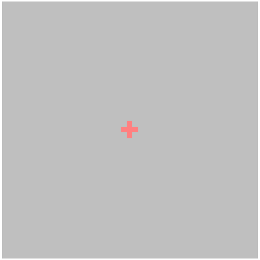
(objective) in this talk, as part of the goal set in WP4T1, my goal is to show that a model-based approach to the definition of stimuli (to be used in physiology, models or hardware) is a sensible control to handle complex and controllable systems

(outline) I will first show our particular implementation, called Motion Clouds, that is adapted to the visual detection of motion. I will present some results and try to convince you to use this tool that is released through NeuroTools to all members of BrainScaleS.

Model-based stimulus synthesis



?

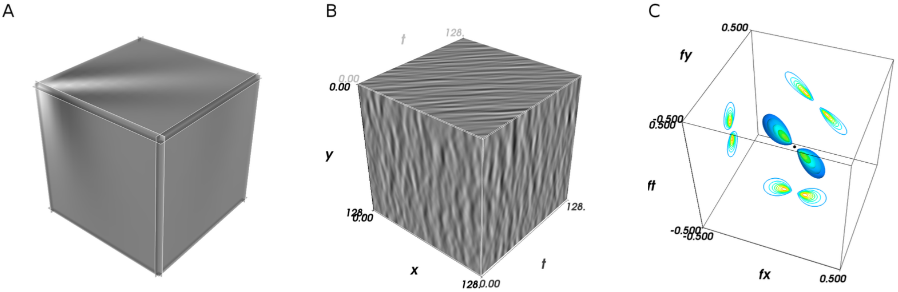


Model-based stimulus synthesis

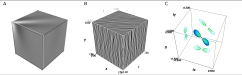
(G) One of the objectives of system neuroscience is to understand how sensory information is encoded and processed in the central nervous system, from single neurons to population of cells forming columns, maps and large-scale networks. There is a long tradition of probing the visual system as a spatiotemporal frequency analyzer. Accordingly, visual neurons have long been tested with drifting gratings in order to characterize both their selectivities and some of non-linear properties of their RF.

(NI) A more recent trend has been to consider sensory pathways as complex dynamical systems. As such, these are able to process high dimensional sensory inputs with complex statistics such as encountered during natural life. As a consequence, the objective in this novel approach is to understand how the visual brain encodes and processes natural visual scenes. Controversial opinions have been proposed on whether natural scenes and movies should be used straightforwardly for visual stimulation or whether one should rather develop new sets of ``artificial" stimuli that would share some of the properties of natural images.

(link) It has become a critical challenge to elaborate new visual stimuli that link these two constraints: being both efficient and relevant to probe high-dimension dynamical systems and being easily tailored so that they can be used to conduct quantitative experiments. Based on the framework of system identification, our aim is to provide such a set of stimuli, that we call Motion Clouds, and that we cast into a well-defined mathematical framework adapted to the study of motion detection.



A
B
C
t
128.
0.00
0.00
y
128
0.00
x
128
0.00
t
128.
0.500
fy
-0.500
0.500
ft
-0.500
-0.500
fx
0.500

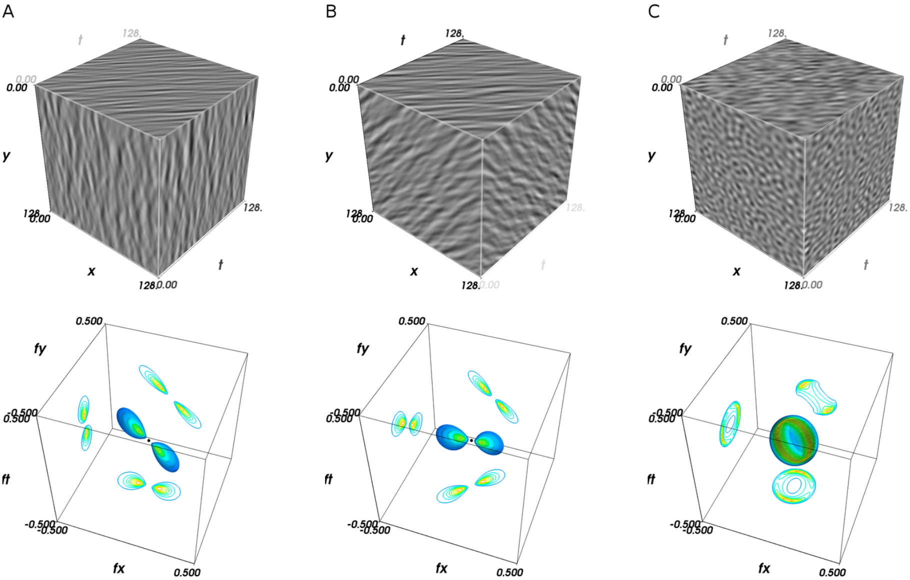


In a nutshell, we define Motion Clouds as the textures with a similar envelope as given by the spatiotemporal filtering properties of a population of V1 or MT neurons such that these stimuli are optimally detected by these energy detectors

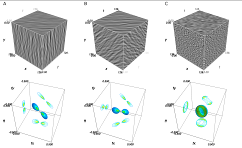
(*A*) The movie corresponding to a typical ``edge", i.e., a moving Gabor patch that corresponds to a localized grating. The Gabor patch being relatively small, for clarity, we zoomed 8 times into the non-zeros values of the image.

(*B*) : By densely mixing multiple copies of the kernel shown in (A) at random positions, we obtain a Motion Cloud.

(*C*) : We show here the envelope of the Fourier transform of kernel *K*: inversely, *K* is the impulse response in image space of the filter defined by this envelope. The spectral envelope of the RPT in (B) is the same as the one of the kernel K shown in (A). Motion Clouds are defined as the subset of such textures whose main motion component is characterized by spectral envelopes concentrated on a plane.



A
B
C
t
128.
0.00
y
x
128.
fy
fx
ft
0.500
-0.500

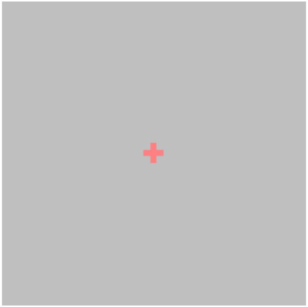


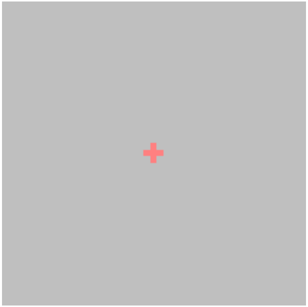
Let's review some concrete examples of Motion Clouds and their equivalent representations with respect to some classical stimuli.

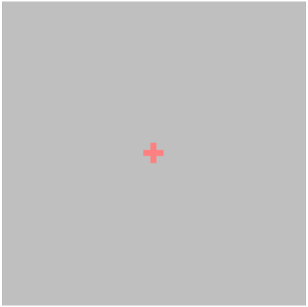
(*A*, *top*) : a narrow-orientation-bandwidth Motion Cloud produced only with vertically oriented kernels and a horizontal mean motion to the right. (*Bottom*): The spectral envelopes concentrated on a pair of patches centered on a constant speed surface. Note that this ``speed plane" is thin (as seen by the projection onto the (f_x,f_t) face), yet it has a finite thickness, resulting in small, local, jittering motion components.

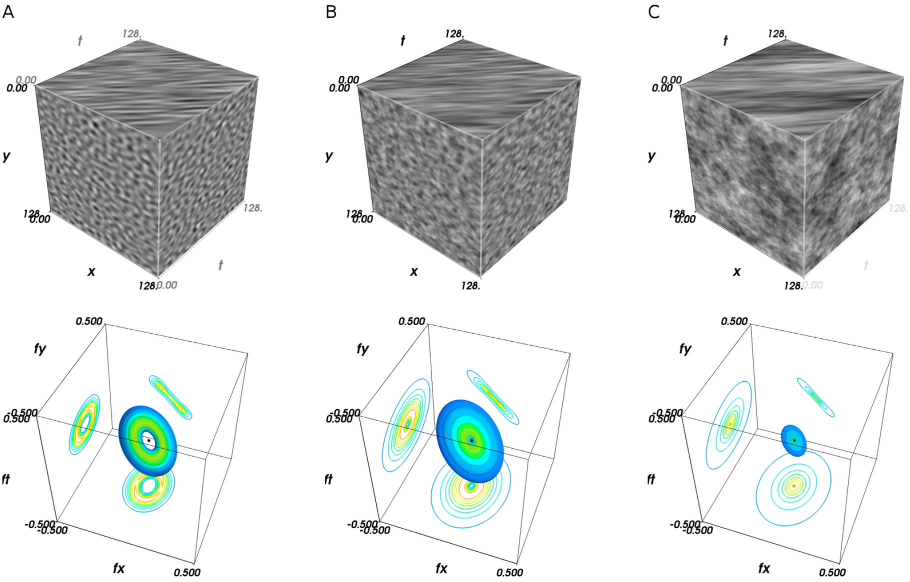
(*B*) a Motion Cloud illustrating the aperture problem. (*Top*): The stimulus, having oblique preferred orientation ($\theta = \frac{\pi}{4}$ and narrow bandwidth $B_\theta = \pi/36$) is moving horizontally and rightwards. However, the perceived speed direction in such a case is biased towards the oblique downwards, i.e., orthogonal to the orientation, consistently with the fact that the best speed plane is ambiguous to detect (Supplemental Movie 2).

(*C*) : a low-coherence random-dot kinematogram-like Motion Cloud: its orientation and speed bandwidths, B_θ and B_V respectively, are large, yielding a low-coherence stimulus in which no edges can be identified.

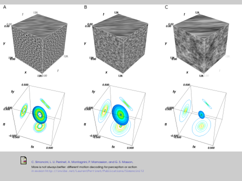








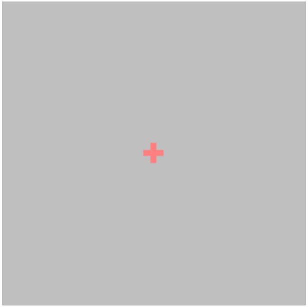
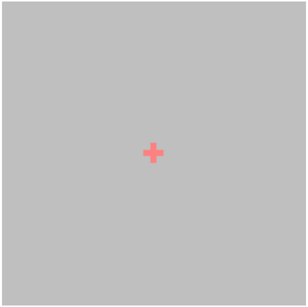
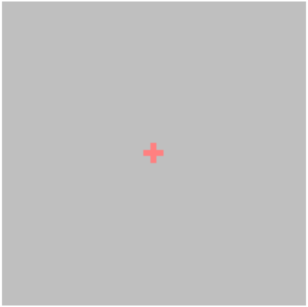
C. Simoncini, L. U. Perrinet, A. Montagnini, P. Mamassian, and G. S. Masson,
More is not always better: different motion decoding for perception or action
In revision http://invibe.net/LaurentPerrinet/Publications/Simoncini12

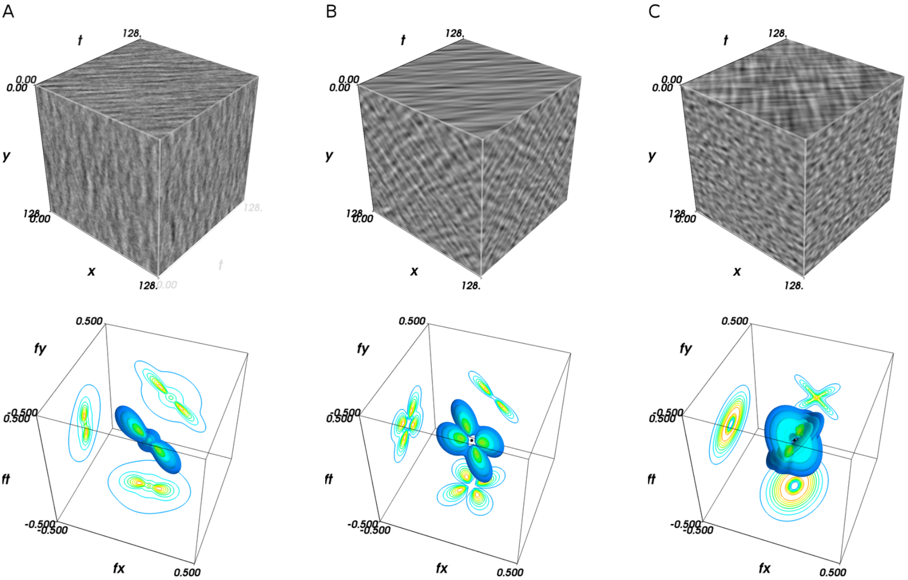


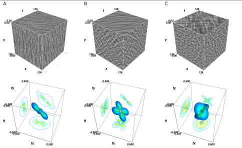
In particular, we have studied in human psychophysics the role of spatial frequency bandwidth. Basically studying Broadband vs. narrowband stimuli allows o better understand the pooling of information from different frequency channels.

(B_{sf}) From (*A*) through (*B*) to (*C*) the frequency bandwidth B_f increases, while all other parameters (such as f_0) are kept constant.

(NI) The Motion Cloud with the broadest bandwidth is thought to best represent natural stimuli, since, as those, it contains many frequency components. (*A*) $B_f = 0.05$, (*B*) $B_f = 0.15$ and (*C*) $B_f = 0.4$.




A
B
C
t
y
x
128.
0.00
fy
ft
fx
0.500
-0.500



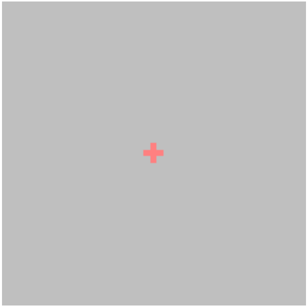
An extension of this framework is to study Competing Motion Clouds, that is the superposition of 2 MCs:

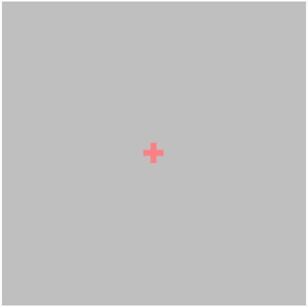
(*A*) : A narrow-orientation-bandwidth Motion Cloud with explicit noise. A red noise envelope was added to the global envelop of a Motion Cloud with a bandwidth in the orientation domain.

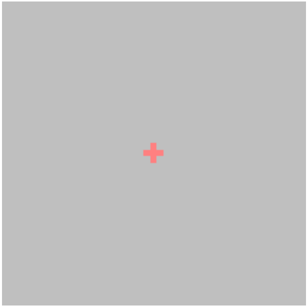
(*B*) Two Motion Clouds with same motion but different preferred orientation were added together, yielding a plaid-like Motion Cloud texture (Supplemental Movie 8).

(*C*) Two Motion Clouds with opposite velocity directions were added, yielding a texture similar to a ``counter-phase'' grating (Supplemental Movie 9). Note that the crossed shape in the $f_x - f_t$ plane is a signature of the opposite velocity directions, while two gratings with the same spatial frequency and in opposite directions would generate a flickering stimulus with energy concentrated on the f_t plane.

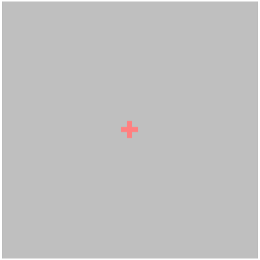
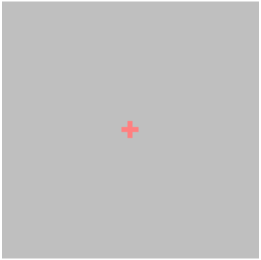
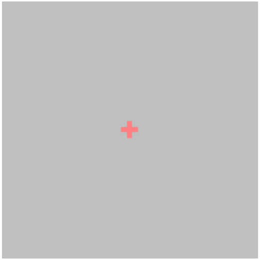
Note that ---contrary to gratings--- there is no interference in the superposition process that would modify the properties of each component.







Take-home message

P. Sanz Leon, I. Vanzetta, G. S. Masson, and L. U. Perrinet,
Motion Clouds: Model-based stimulus synthesis of natural-like random textures for the study of motion perception
Journal of Neurophysiology http://invibe.net/LaurentPerrinet/Publications/Sanz12

To summarize, during this talk I hope I convinced you that

- it is possible to define model-based stimuli and these constitute useful controls
- we have developed Motion Clouds as stimuli adapted to the visual detection of motion. We have further perspectives in WP4T1 to develop for more complex generative models and to translate these stimuli to whisking
- To conclude, we hope that you are convinced and that you will actually use it. For that purpose, we have released the code to integrate it to NeuroTools for members of BrainScales. I will happily help anybody who would need it.

Thank you for your attention.

References

P. Sanz Leon, I. Vanzetta, G. S. Masson, and L. U. Perrinet,
Motion Clouds: Model-based stimulus synthesis of natural-like random textures for the study of motion perception
Journal of Neurophysiology http://invibe.net/LaurentPerrinet/Publications/Sanz12

C. Simoncini, L. U. Perrinet, A. Montagnini, P. Mamassian, and G. S. Masson,
More is not always better: different motion decoding for perception or action
In revision http://invibe.net/LaurentPerrinet/Publications/Simoncini12

For Further Reading

G. S. Masson and L. U. Perrinet.
The behavioral receptive field underlying motion integration for primate tracking eye movements.
Neuroscience and biobehavioral reviews, March 2011.

L. U. Perrinet and G. S. Masson,
Modeling spatial integration in the ocular following response using a probabilistic framework.
Journal of Physiology (Paris)
URL `http://invibe.net/LaurentPerrinet/Publications/Perrinet07neurocomp`
2007.

L. U. Perrinet
Role of homeostasis in learning sparse representations.
Neural Computation, 22(7):1812--36, July 2010.

L. U. Perrinet, and G. S. Masson
Motion-based prediction is sufficient to solve the aperture problem
Under revision `http://invibe.net/LaurentPerrinet/Publications/Perrinet12pred`

Y. Weiss, E. P. Simoncelli, and E. H. Adelson.
Motion illusions as optimal percepts.
Nature Neuroscience, 5(6):598--604, Jun 2002.

Motion Clouds: Model-based stimulus synthesis of natural-like random textures for the study of motion perception

Model-based stimulus synthesis

MotionClouds: natural-like random textures

Take-home message