Pre-attentive Vision Models for Automated IMAGE/RPI Data Exploration

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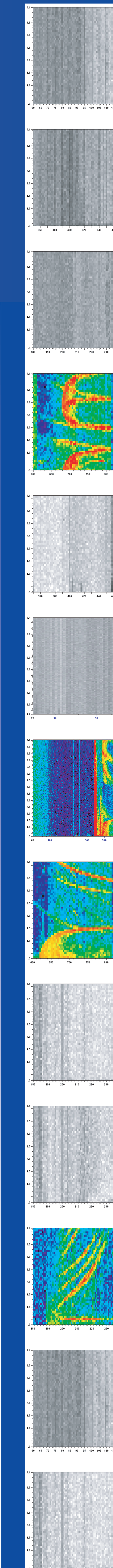
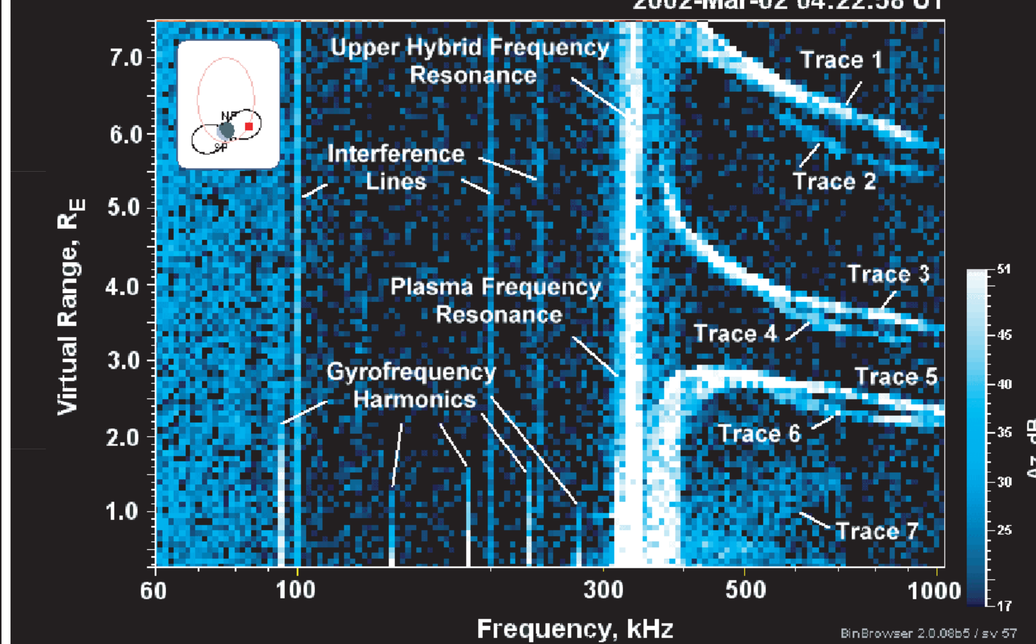
UMass Lowell Center for Atmospheric Research

http://car.uml.edu/rpi/corpral/

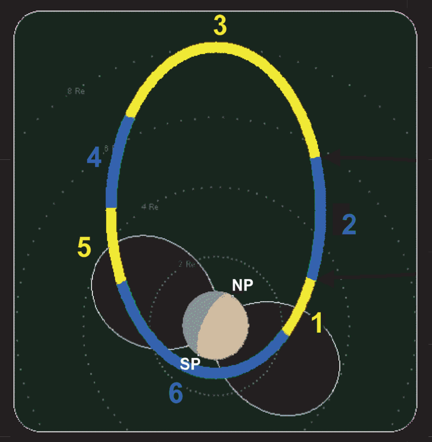


RPI PLASMAGRAM



Traces and resonances identification in plasmagram signatures

PROJECT MOTIVATION



Six regions of the RPI orbit with different scientific tasks and measurement modes

Few plasmagrams (less than 15%) contain signatures

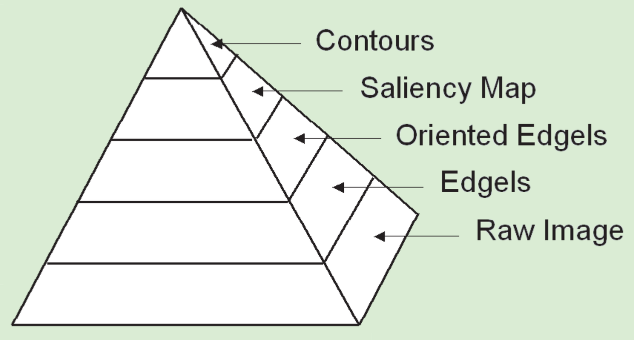
The total projected volume for the Radio Plasma Imager (RPI) mission is about 1.5 million plasmagrams, collected at about 600 per day. Less than 15% plasmagrams contain signatures, requiring a tedious data exploration effort to locate them.

The RPI adjusts its measurement parameters constantly, depending on its position in orbit. This results in a highly variable and irregular data stream, making even cartoon movies impossible. Browsing such a plasmagram archive even at 1 per second would take well over 2 months!

We propose a solution through an intelligent pre-classification system that selects plasmagrams containing signatures of particular interest.

PRE-ATTENTIVE VISION PARADIGM

Salient objects are detected bottom-up from image pixels to object contours, successively, by building elements of increasing perceptual strength.



Marr's Pyramid of Perception

Marr, D. and H.K. Nishihara, Visual information processing: Artificial intelligence and the sensorium of light, *Tech. Review*, **81**, 2-23, 1978.

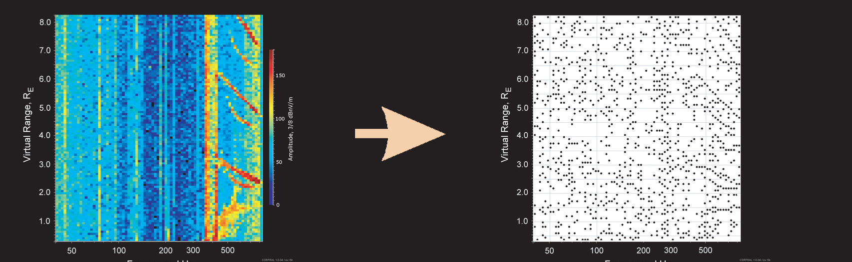
Edgels: "edge elements", introduced in the visual scene analysis where objects are analyzed by first locating their boundaries (edges). The edgel corresponds to a sharp gradient in the image intensity typical of a boundary. Individual edgels form the contour.

Oriented Edgels: Evaluation of local orientation of the contour at the edgel location adds an additional perceptual value to edgels. The edgel orientation is commonly obtained by seeking gradients of image intensity within a local context window around the edgel.

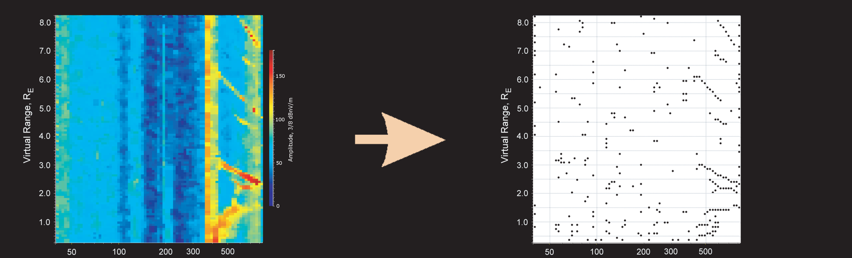
Saliency Map: Local context techniques do not yield reliable edgel orientations in various situations requiring a larger context area to correctly identify the trace. Long-range, collective analysis of edgel data results in evaluation of perceptually stronger quantity, saliency. The saliency measure reflects how likely an edgel is part of a contour. Saliency measures calculated for all edgels constitute the saliency map of the image.

Contours: The saliency map is analyzed to find subsets of edgels belonging to the same contour. Found subsets may correspond to contour segments that could and need to be completed into full contours, but this typically represents an operation outside the scope of pre-attentive vision.

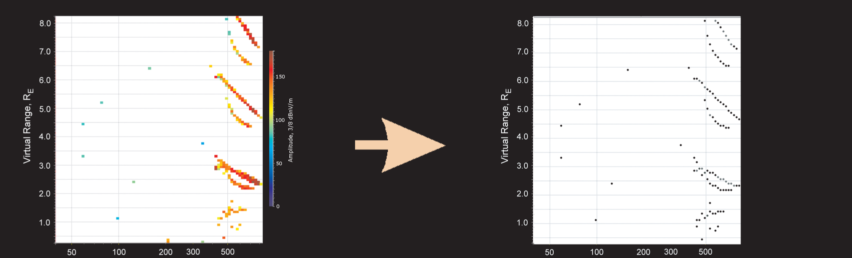
EDGEL DETECTION



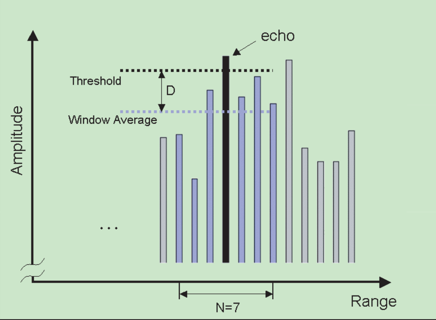
DIRECT DETECTION WITH CONTRAST LIMIT



CLASSIC SMOOTHING

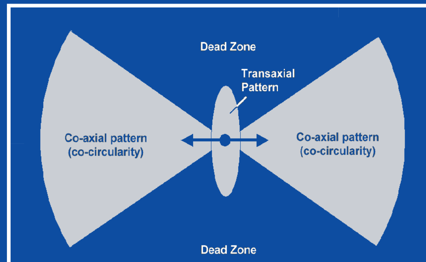


1D ADAPTIVE ECHO DETECTION



The echo detection algorithm labels a pixel *i* as echo if its amplitude Ai exceeds a threshold value Ti calculated over a enclosing window of size N placed at the tested pixel. The threshold value is set to the average amplitude within the window (excluding the pixel i itself) plus a fixed value D. The algorithm is designed to detect signals above the noise level that are narrow enough to fit within the window and leave room for the background amplitudes that produce the threshold value. The 1D window is placed on the plasmagrams vertically to avoid influence of the neighboring frequencies that may have significantly different levels of noise and signal.

SALIENCY CALCULATIONS

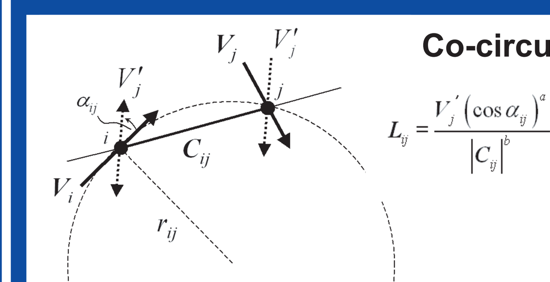


Yen, S.C. and L.H. Finkel, Extraction of perceptually salient contours by striate cortical networks. Vision Research, 38, 719-741, 1998.

Rock, I. and S. Palmer, The legacy of Gestalt psychology, Sci. American, SCA9012, 84-90, 1990.

Saliency measure is calculated for each edgel by counting contributions from other edgels in its vicinity under guidance of the Gestalt principles of perception. The saliency measure is higher if nearby edgels form a long and smooth contour and lower if edgels form a short and wiggly contour (Gestalt's principles of *good continuation*, *co-circularity*, and *proximity*). The calculations are done in a neural network where each neuron state is affected by many other neurons through a system of synaptic weights that enforces the Gestalt constraints. The synaptic weights are changing dynamically depending on mutual orientation of oriented edgels (rotors) and distance between the edgels. We use a version of Yen and Finkel model of cortical network for interacting rotors.

Co-circular Interaction in Coaxial Zone

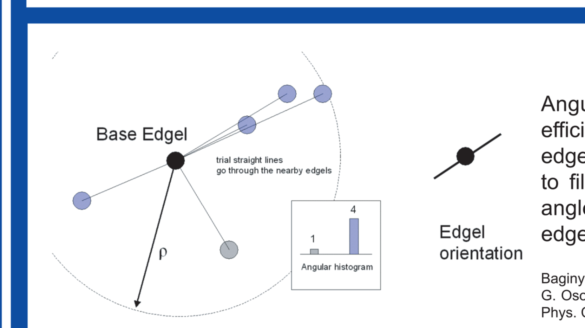


$$L_{ij} = \frac{V'_j \left(\cos\alpha_{ij}\right)^a}{\left|C_{ij}\right|^b}$$

Rotor **V'**$_j$ is obtained by flipping **V**$_j$ around the chord **C**$_{ij}$

Contribution maximizes when both rotors are tangential to the circle of radius r_{ij} (Gestalt co-circularity).

Angular Histogramming



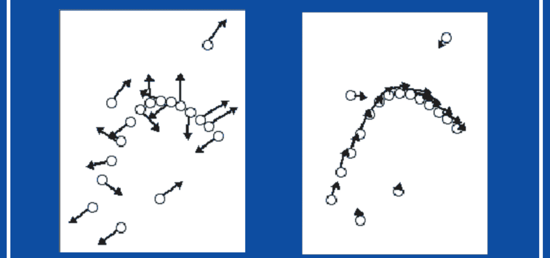
Angular histogramming technique (AHT) is an efficient implementation of the steerable filter for edgel patterns. AHT fits trial lines through edgels to fill a histogram of angles; the most probable angle is selected as the local estimate of the edgel orientation.

Baginyan, S., A. Glazov, I. Kisel, E. Konotopskaya, V. Neskoromnyi, and G. Ososkov, Tracking by a modified rotor model of neural network, Comp. Phys. Comm., 79, 165-178, 1994.

Extraction of Segments from Saliency Map

Once the rotor orientations are optimized, contour segments are extracted by the bottom-up clusterization. The clusterization groups the edgels starting with the highest saliency down to the pre-specified lower limit.

ROTOR OPTIMIZATION



Before optimization

After optimization

Most of existing saliency calculation schemes use static orientations of egdels without attempting to modify them. Errors in local estimates of the edgel orientation cause errors in placement of the interaction pattern and wrong calculation of the saliency.

The saliency evaluation task can be treated as iterative optimization problem aiming to maximize saliency measures over possible edgel orientations by allowing oriented edgels (rotors) change their angle and length in response to the facilitating inputs from other rotors. The optimization task is solved within the energy minimization approach by an iterative feedback Hopfield neural network with the Mean Field Theory (MFT) processing of neuron outputs and an adaptive simulated annealing scheme to keep evolving process from saturating and fading.

Peterson, C., Track finding with neural networks, Nucl.Instr.Meth.Phys.Res., A279, 537-545, 1989.

Peterson, C. and J.R. Anderson, A mean field theory learning algorithm for neural networks, Complex Systems, 1, 995-1019, 1987.

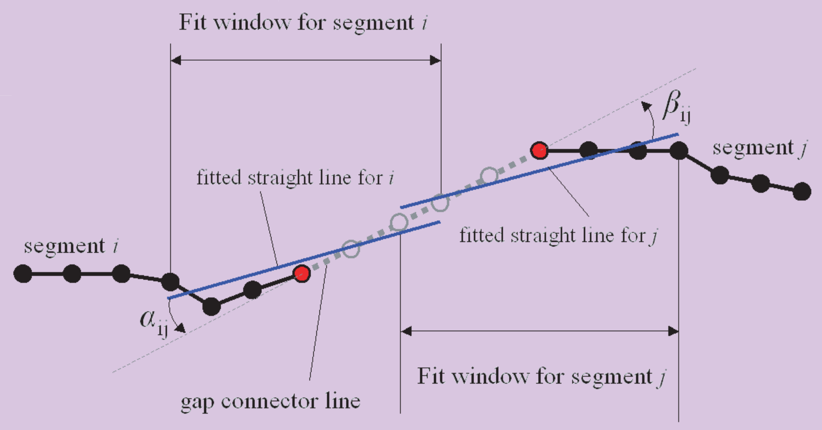
Galkin, I.A., B.W. Reinisch, G.A. Ososkov, E.G. Zaznobina, and S.P. Neshyba, Feedback neural networks for ARTIST ionogram processing, Radio Sci., 31, 1119-1129, 1996.

PERCEPTUAL GROUPING

Contour segments *i* and *j* are combined if their combination score Q_{ij} is smaller than a threshold value and is the smallest among all segment pairs:

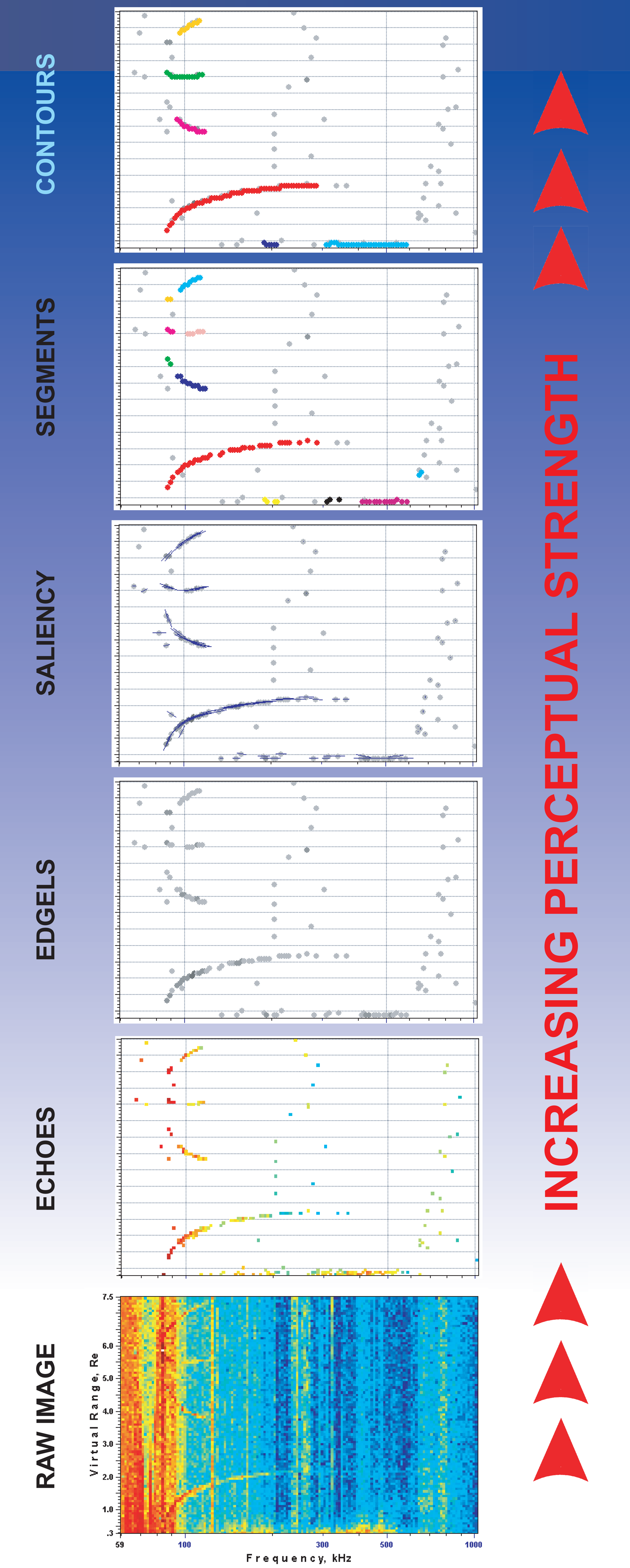
$$Q_{ij} = \lambda A_{ij} + \left(1-\lambda\right) G_{ij} = \lambda\sqrt{\frac{\alpha_{ij}+\beta_{ij}}{\pi}} + (1-\lambda)\frac{d_{ij}}{D}$$

A_{ij} - connection smoothness term
G_{ij} - connection gap term
λ - contribution adjustment coefficient
d_{ij} - gap length
α_{ij} and β_{ij} - angles calculated from the segment geometry:



CORPRAL

Cognitive
Online
Rpi
Plasmagram
Ranking
ALgorithm



SUMMARY

"CORPRAL" is an IDU system that explores daily submissions of the Radio Plasma Imager data looking for certain signatures (echo traces). Found qualifying plasmagrams are rated in the mission database. The CORPRAL selects about 15% of all images (currently ~100,000).

CORPRAL employs a pre-attentive vision model to extract contours of the signatures. The model detects edge elements and evaluates whether their saliency is sufficient to select them as contour segments.

Developed approach can be applied to other areas of IDU to detect signatures in the output of visual sensors.

PUBLISHED WORK:

Galkin, I., B. Reinisch, G. Grinstein, G. Khmyrov, A. Kozlov, and S. Fung, Automated Exploration of the Radio Plasma Imager Data, 2004 (submitted to JGR Blue)

Galkin, I., B. Reinisch, X. Huang, R. Benson, and S. Fung, Automated Diagnostics for Resonance Recognition in IMAGE/RPI Plasmagrams, Radio Science, 2004 (in press)

Galkin, I., G. Khmyrov, A. Kozlov, B. Reinisch, X. Huang, and G. Sales, New tools for analysis of space-borne sounding data, Proc. 2001 USNC/URSI Nat. Radio Sci. Meeting, Boston, MA, 304, 2001.