## Collaborative Research Team ideas

Features and Meaning. What distinguishes useful images from the space of all possible data objects of any given size? Although human vision is remarkable for the detection of many features, we are relatively poor at finding features that are separated in space, that evolve in time, or are characterized by low spatial or temporal frequencies. Parameters such as sparsity, non-gaussian independent components, coherence, edges and steep gradients all have given considerable leverage in areas such as pattern analysis and compressed sensing, particularly in two dimensional imaging. This project will explore several related, but little-studied, areas. Projection of images into a sparsely-populated feature space can serve as a dimension reduction step in machine learning algorithms: both principal and independent components analysis (PCA and ICA) have been used to this end. They both have the feature of the detection of non-local structure that often is invisible to the eye. Compactness, however, is only one possible optimization. For discovery from images, it is also important that the feature space be interpretable in the context of the data domain. We have shown, for example, that ICA is a preferable (by comparison to PCA, or individual voxels) basis set for machine methods of studying cognitive process by MRI, as the resultant hidden layers are readily interpretable by neuroscience experts. In other cases, optimizing data compression or classification may be a preferred endpoint. Compactness also is important in data representation: In general, it is desirable to present data in a manner that shows its information-bearing features.

The extrapolation of these methods to multi-modal or hyperspectral data will be another research goal of this CRT, as is the problem of data alignment in the case that the native data axes are incommensurate or where the data are acquired over entirely different domain spaces, such as neuroelectric potentials metric image spaces such as photographic or medical tomographic data.

A further objective of this team will be to study the use of generative models for dimensional reduction and compaction, both in the image space where relations among data points might be inferred by pattern analysis, and in the data domain, where generative rules might control large scale phenonema as such the growth of galaxies, brains or molecules. Fractal analysis might be one method for such feature extraction, as might expert knowledge of defining physical principles such as mechanics of the objects under study. It may become possible to examine phenotypic expression by relating growth parameters to genetic analysis.

The highly interdisciplinary team for this work includes

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Giovanni Coppola (neurology)
Kevin Kelly (electrical and computer engineering – Rice U)
Klaus Müller (mathematics)
Stan Osher (mathematics)
Joey Teran (computer science)

Dimensions: Scientific images, tend to be compressed representations of the data they represent. This compression is bidirectional: at times our instruments "see" in 2D, and the problem is one of dimensional expansion. At other times the data we acquire through instruments is highly dimensional (e.g., space, time, frequency) and/or hyperspectral (multiple energy bands, mass, statistical variance) so that the challenge is the efficient projection and or fusion of data across dimensions to both represent and to explain information bearing features of images. Beyond the straightforward problems of projective transformation of three dimensional objects onto two dimensional space, This CRT will study problems of dimensionality in multiple forms. How does the brain represent space? What are the elemental features of image representations that allow the transformation of images to space? How can we navigate and interact with images of high dimensionality?

Andrea Bertozzi (mathematics)
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Unlimiting Resolution. Limitations to spatial and temporal resolution in imaging have, in many cases, been well-known for decades – but the assumption on which they are based have not been challenged systematically. The technological changes that accompany today's imaging have resulted in the formation of images whose resolution exceeds the canonical limitations of electromagnetic wavelength, point spread functions, fourier limits, wavefront distortions and other presumed barriers. Such technologies include adaptive optics, super-resolution optical fluctuation imaging, maximum likelihood estimators and others, many of which were created by the faculty of ISEG. At the same time, the temporal resolution of imaging, being limited by the speed of image read-out circuitry as well as the fundamental tradeoff between noise and bandwidth, has only recently begun to be addressed. This collaborative research team will consider the translation of these breakthrough technologies across domains of imaging from the femtometer and femtosecond to the light year scale.

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Growth and Change. Time is an important component of the scientific image. It is used to convey additional dimensionality by spatial transformation of objects, and to display process and evolution. The shape of the human brain changes with age, use and disease in ways that are difficult to capture in tables and graphs, but which offer important clues to the underlying process, Most astronomical images are odd temporal constructs the give the appearance of a non-existent simultaneity. The focus of this collaborative research team will be on the quantitative assessment and representation of change. We will create and consolidate methods for registration across time and space. We will develop metrics that express morphological and other changes. We will consider the problem of deriving generative rules from the observed data, such as those that cause objects to take the forms of galaxies and of folds in the neocortex. We will seek to understand the coupling between features such as these and the genetics that drive them in living organisms.

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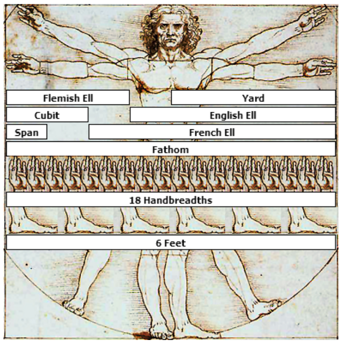


<u>The Role of Aesthetics in Scientific Imaging</u>. Leonardo da Vinci's "The proportions of man" is one of the most reproduced scientific images; it attracts us for its singular beauty. As he noted in the accompanying text, with it da Vinci attempted to convey established facts, "a man's height is 4 cubits (and thus 24 palms)" and, "the length of a man's outstretched arms is equal to his weight." Beautiful often find their way into the lay press and elevate the findings that they illustrate, where unsightly images might discourage readership. The most successful of these images become canonical and often establish conventions that become a vocabulary for communication. The conventions that are used in images to describe scientific data often seem arbitrary to the scientist, but hold meaning to the viewer: blue to red/yellow color scales tend to convey the "importance" of the features presented in the warm colors. The well-known ball and stick figures of the fullerenes invite their interpretation as soccer balls, whose physical/mechanical properties are entirely different. This CRT is both deconstructive and constructive. We will study the dual-edged influence of aesthetic choices in scientific images and will work to make scientists aware of the implied meaning of the conventions that they use in presenting data with the aim of creating images that minimally distort the concepts they represent, while simultaneously creating impact.

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Seeing. Although the idea of imaging is expanding to encompass multi-sensory representations, in most cases we equate images with vision. Vision as a sensory channel is limited significantly by the neural machinery of vision. This CRT will consider the problem of capitalizing on knowledge of the visual system to design data representations that are tuned to the human visual apparatus. For example, current data suggest that we integrate multiple sensory streams in a fashion that appears as an ideal Bayesian observer. With this knowledge, one can optimize the relative fidelity (variance structure, blur, etc…) of multiple data components to aid the integration of information: How much information should be conveyed through channels of color, spatial orientation, motion, etc… to optimize the density of information transfer.

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