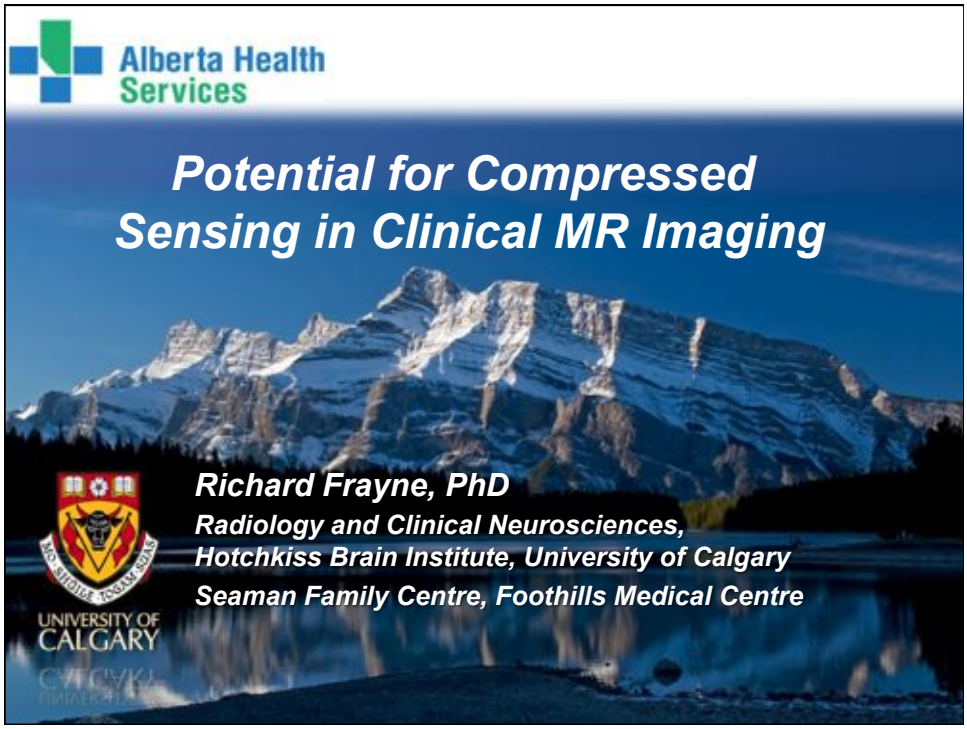

Outline

- MR Imaging – Acquisition and Reconstruction
  - resolution
  - signal-to-noise
  - total acquisition time
- Image Compression
  - compressed sensing
  - maximising trade-off the between resolution, SNR and total acquisition time
- Clinical applications
  - scanning faster with higher resolution and better SNR

Magnetic Resonance (MR) Imaging

- Non-invasive <u>clinical</u> imaging modality
  - visualization of anatomic <u>structure</u>
  - investigation of body <u>functions</u>
- Detection or staging of numerous diseases
  - cancer, cardiac disease, stroke, *etc.*
- Sensitivity to detect pathologies (disease) relies heavily on quality of acquired images, *e.g.,*
  - spatial and temporal resolution, signal-to-noise ratio
  - total acquisition time
  - image contrast and artifacts, …

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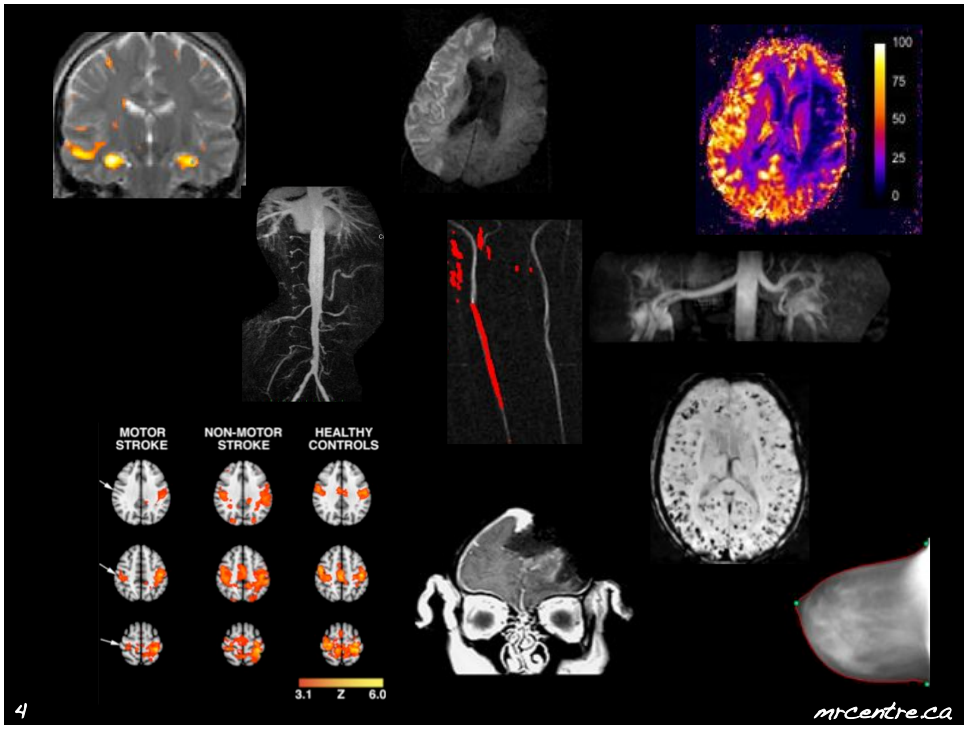

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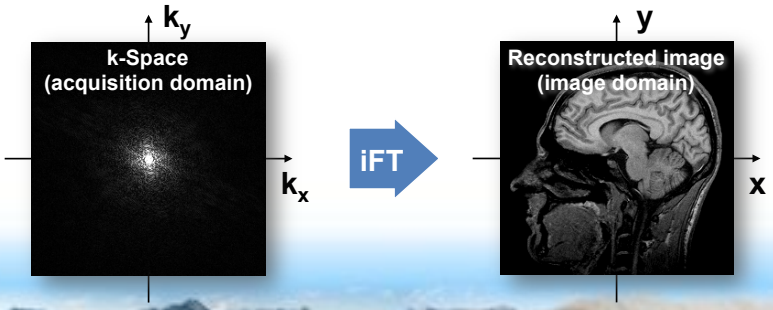
Conventional MR Imaging

- Data acquisition requires complete and uniform sampling of k-space
- Reconstruction by inverse Fourier transform (iFT)
- Acquisition of complete k-space is slow
  - can limit spatial and/or temporal resolution



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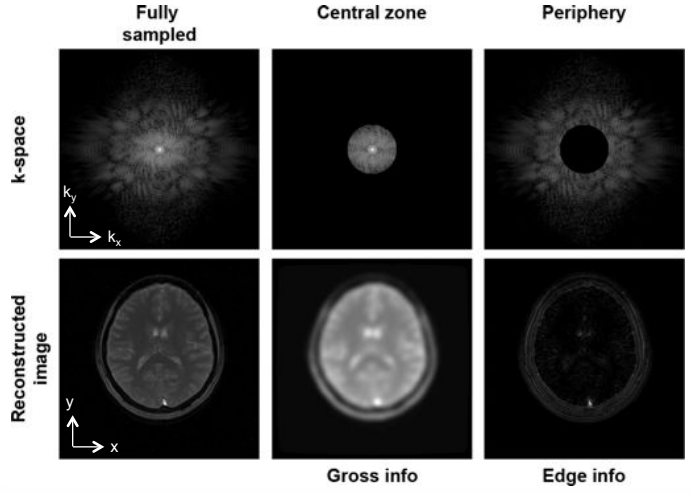
Important k-Space Properties



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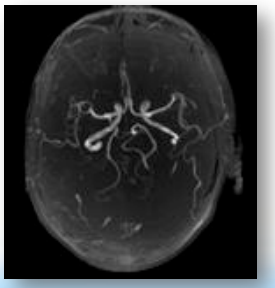
The Tradeoff in MR Angiography

- Critical tradeoff between spatial resolution, acquisition time and SNR
- Typical coverage: 20 cm × 20 cm × 10 cm

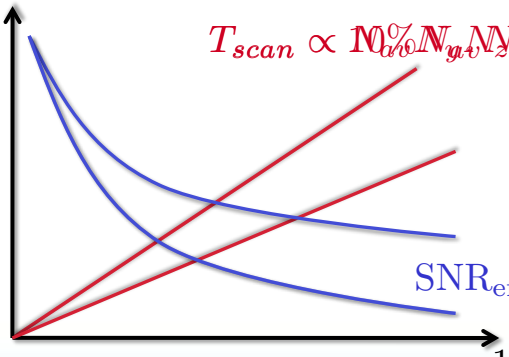


Acq matrix = 256×256×150
Resolution = 781 µm × 781 µm × 2 mm
Scan time = 4.69 min
SNR = 100%
SNR_{eff} = 100%

$$\mathrm{SNR} \propto \Delta_v \sqrt{T_{acq}}$$

$$\mathrm{SNR}_{\mathrm{eff}} = \frac{\mathrm{SNR}}{\sqrt{T_{acq}}} \propto \Delta_v$$

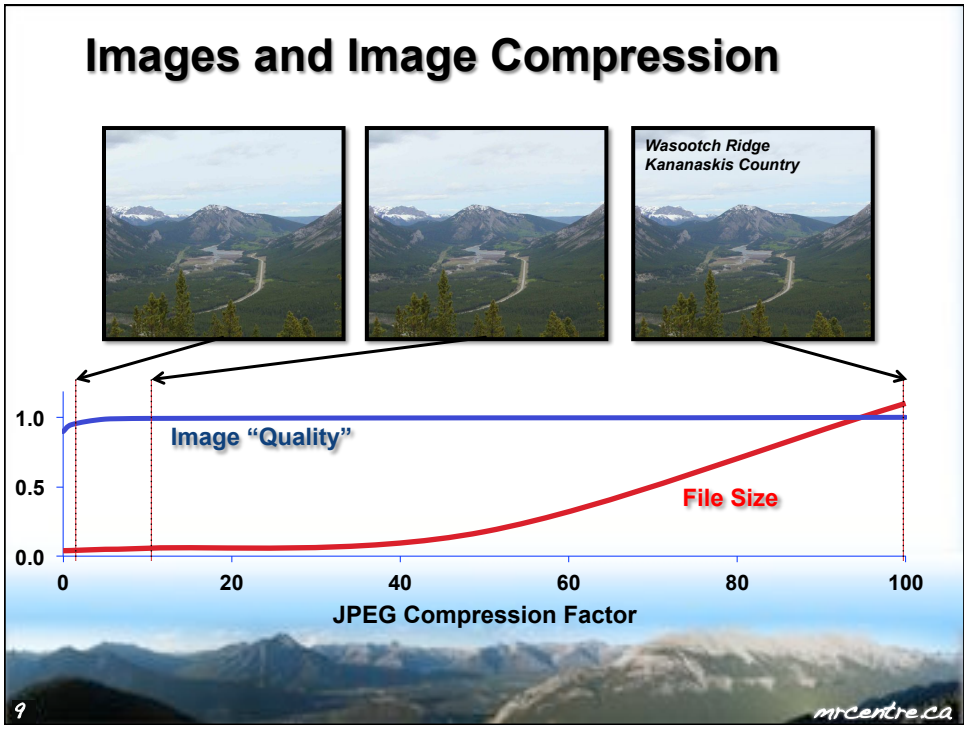
Scan Time and SNR Efficiency



$$T_{scan} \propto N_{av} N_y N_z \mathrm{TR}$$

$$\mathrm{SNR}_{\mathrm{eff}} = \frac{\mathrm{SNR}}{\sqrt{T_{acq}}} \propto \Delta_v$$

$$\mathrm{Resolution} = \frac{1}{\Delta_v}$$


Images and Image Compression
Wasootch Ridge
Kananaskis Country
1.0
0.5
0.0
Image "Quality"
File Size
0
20
40
60
80
100
JPEG Compression Factor
9
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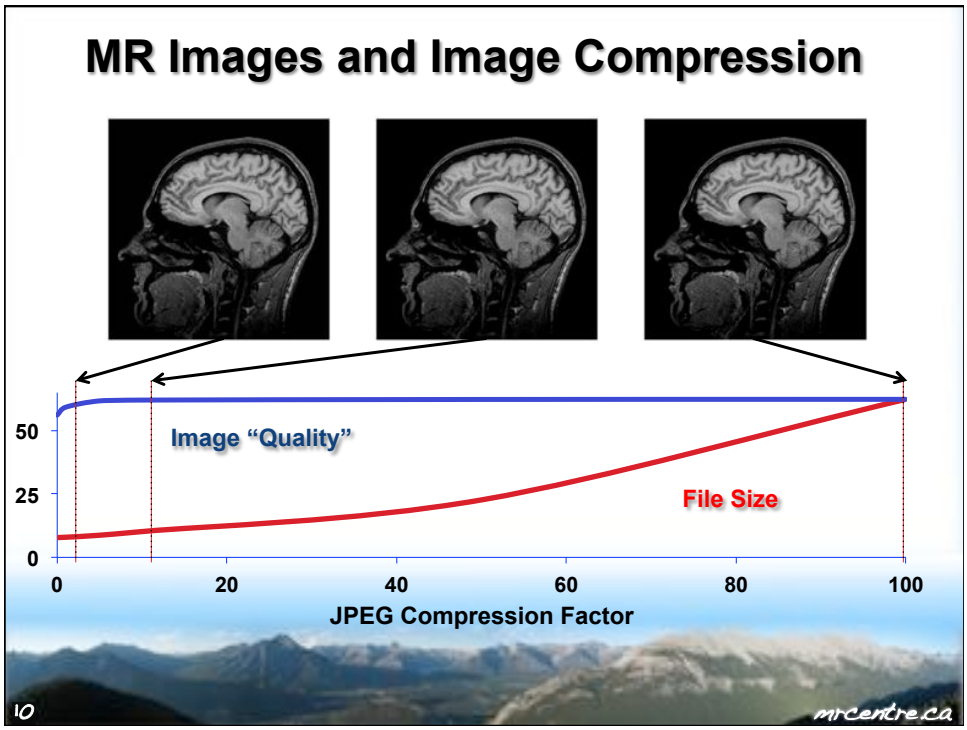
MR Images and Image Compression
50
25
0
Image "Quality"
File Size
0
20
40
60
80
100
JPEG Compression Factor
10
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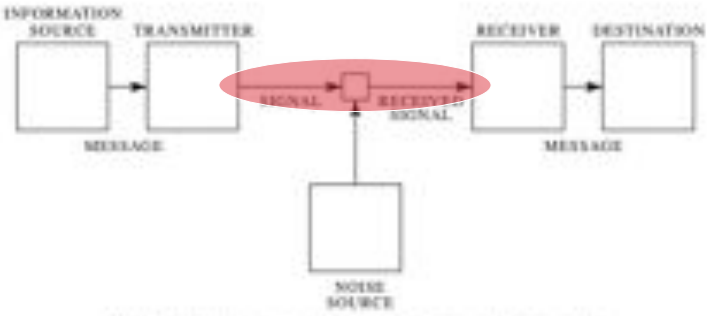
Reprinted with corrections from *The Bell System Technical Journal*, Vol. 27, pp. 379–423, 623–656, July, October, 1948.

A Mathematical Theory of Communication

By C. E. SHANNON



What is the minimum amount of data that need to sent over the communication channel that allows for accurate reconstruction of the original signal?

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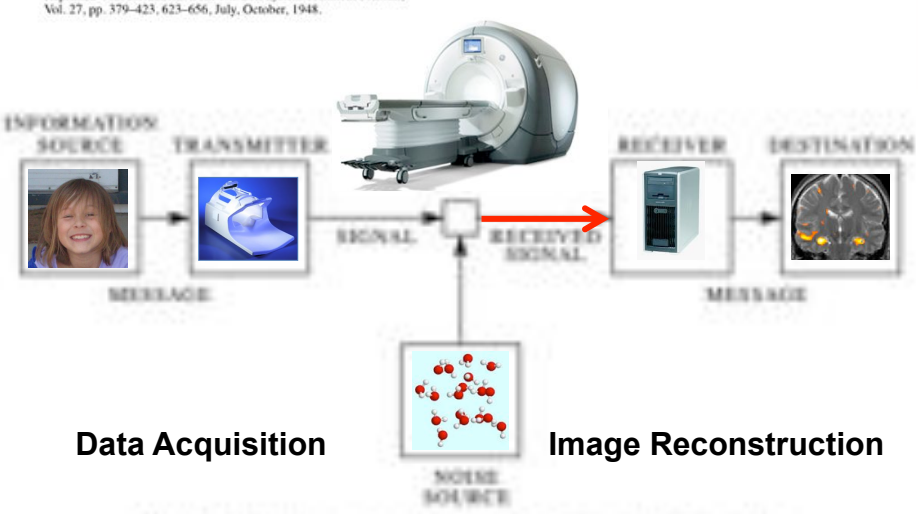
Reprinted with corrections from *The Bell System Technical Journal*, Vol. 27, pp. 379–423, 623–656, July, October, 1948.



Data Acquisition **Image Reconstruction**

What is the minimum amount of data that need to sent over the communication channel that allows for accurate reconstruction of the original object?

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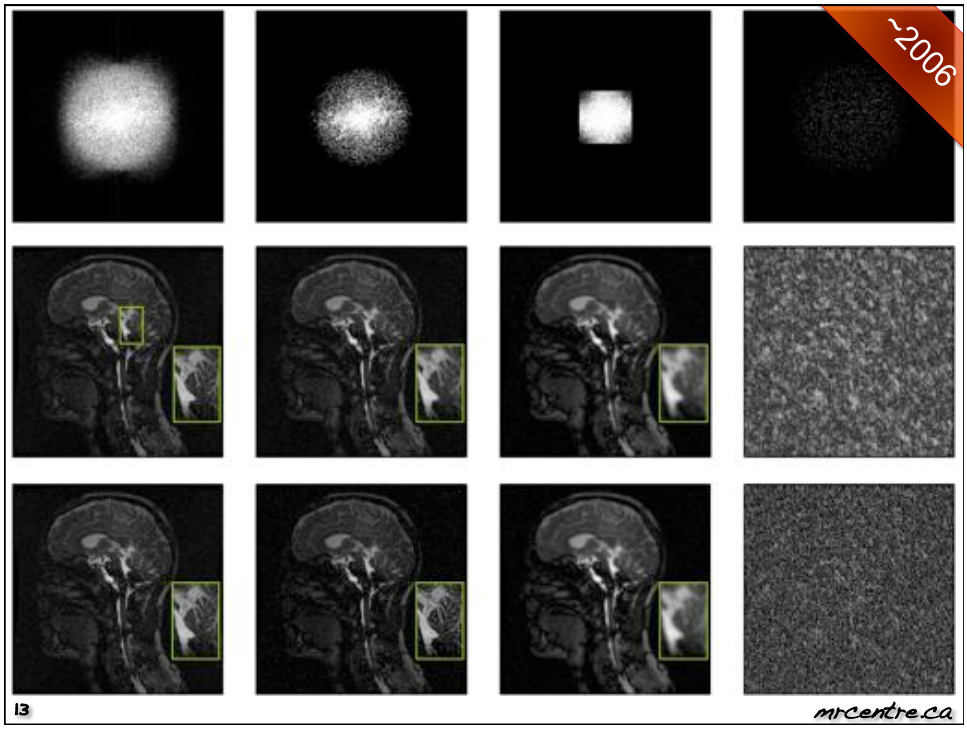

Compressed Sampling (CS)

- Mathematical framework for understanding reconstruction from partial samples
  - Candes and Tao, 2006
  - Donoho, 2006
- Nyquist-Shannon sampling theory states that
  - number of Fourier samples = number of pixels
- Compressed sampling theory suggests that it is possible to reconstruct accurate images from fewer samples

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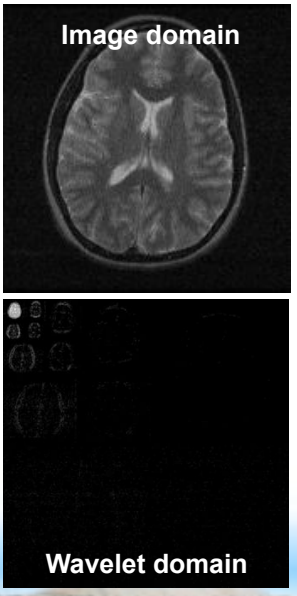
CS Requirements

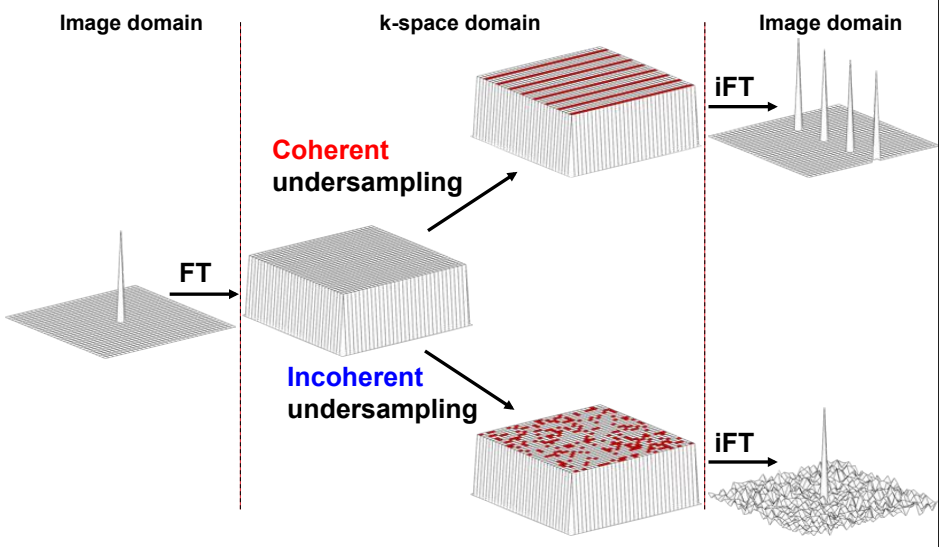
1. Transform sparsity
2. Incoherence of aliasing interference due to undersampling
3. Non-linear iterative reconstruction algorithm

1. Transform Sparsity

- Sparse representation
  - few large coefficients, many small coefficients
- Sparsity via a transform domain
  - discrete cosine transform (DCT),
  - wavelet transform,
  - finite differences, *etc.*



2. Incoherence of Aliasing



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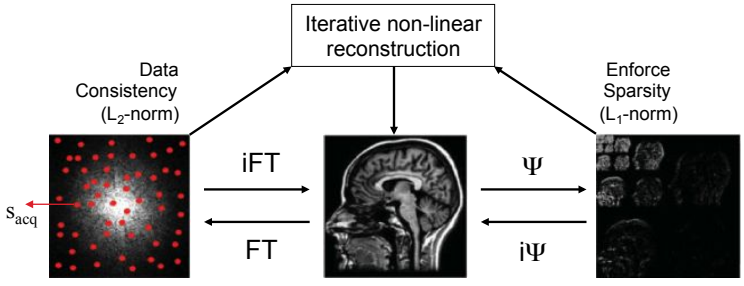
3. Nonlinear Image Reconstruction



$$\text{minimize } \|\Psi\{I(\mathbf{r})\}\|_1$$
$$\text{s.t. } \|\mathrm{FT}\{I(\mathbf{r})\} - s_{acq}\|_2 \leq \varepsilon$$

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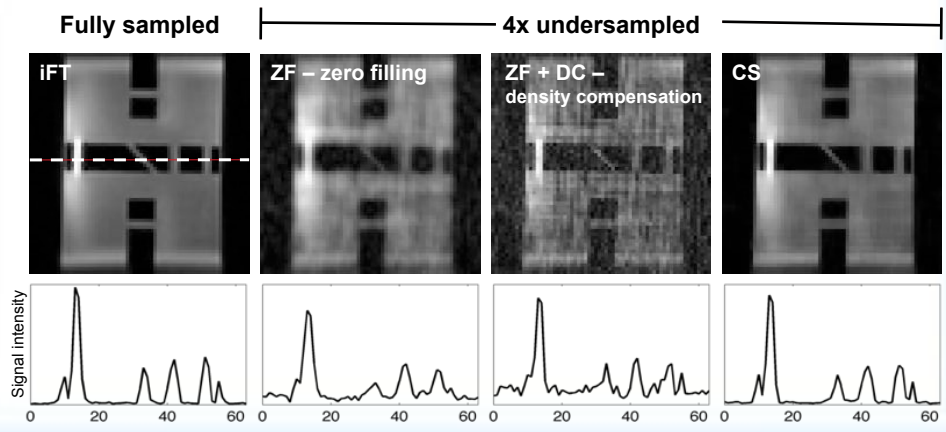
Phantom Images



CS yielded higher SNR and resolution than both ZF approaches!

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Compressed Sensing

- Long history of undersampled MR imaging work
  - POCS,
  - RIGR,
  - HYPR, *etc.*
- CS is a new horizon
  - Candes and Tao, 2006
  - Donoho, 2006

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"Fast" MR Imaging

- Imaging dynamic phenomena
  - cardiac imaging
  - functional imaging
- Shortening length of imaging protocol
- Increasing image resolution
- Patient comfort
- Minimizing patient motion artifacts
- Surgical intervention
- MR guided catheter-based therapy

Compressed Sensing may open up new opportunities for "fast" MR

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Design Goals for Undersampled MR

Accurately reconstructed the image

- Any errors must be obvious
- Image contrast is preserved
- Artifacts (*e.g.*, due to motion) must be well understood

Secondary

- Reconstruction time must be short

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Alberta Health Services

Catheter Visualisation for Endovascular MR using Compressive Sampling

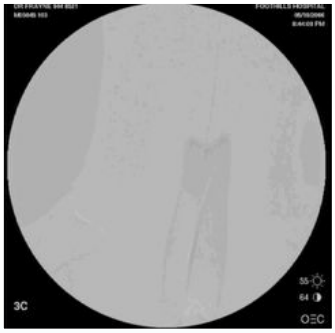
Jerome Yerly[1,2], M Louis Lauzon[1,3], Henry S Chen[1,2], Richard Frayne[1,2,3]

[1]Seaman Family MR Research Centre, Foothills Medical Centre
[2]Department of Electrical and Computer Engineering, University of Calgary,
[3]Departments of Radiology and Clinical Neurosciences, University of Calgary, Calgary, Alberta, CANADA

UNIVERSITY OF CALGARY

Endovascular Intervention

- Treatment of vascular diseases
- Minimally invasive
- Catheter-based procedures
- Device / drug deployment
- Catheter guiding
- Real-time imaging
  - X-ray (gold standard)
  - MR imaging
  - 10 Hz image rates



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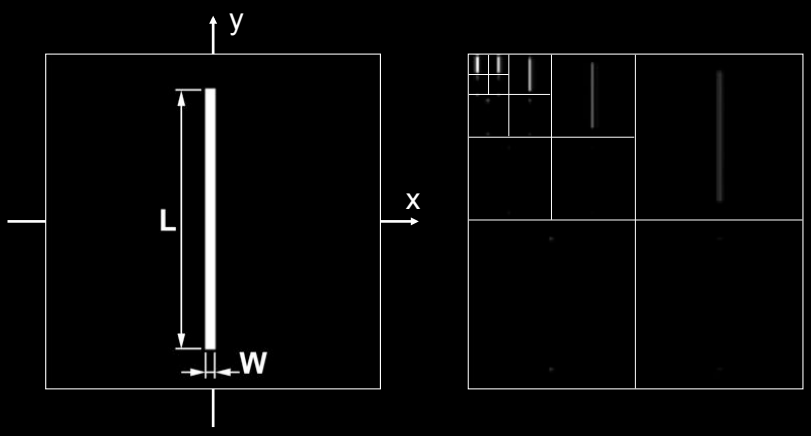
Sparsity in Transform Domain



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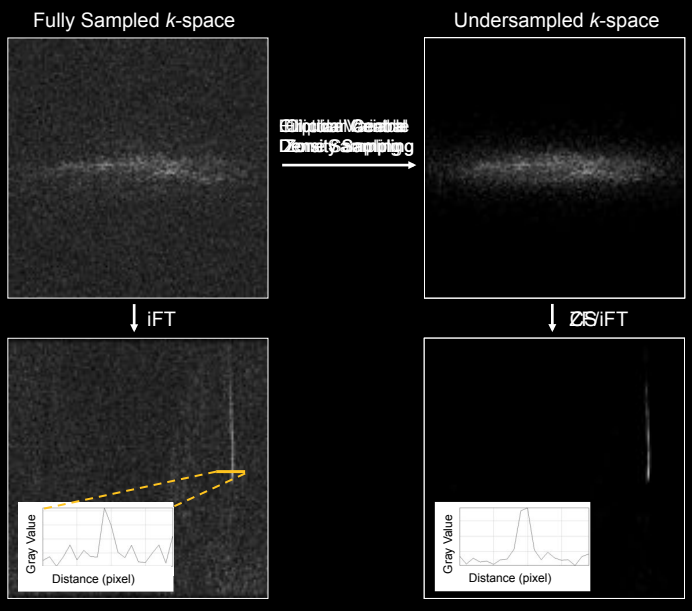
Zero Filling (ZF) versus CS



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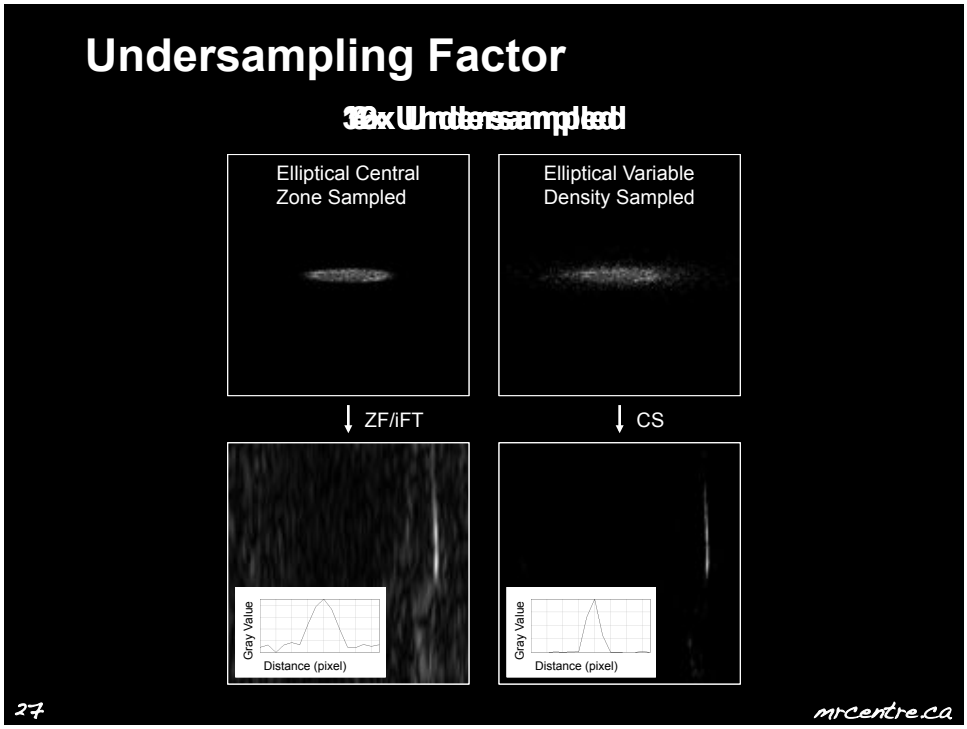
Undersampling Factor
Elliptical Central Zone Sampled
Elliptical Variable Density Sampled
ZF/iFT
CS
Gray Value
Distance (pixel)
Gray Value
Distance (pixel)
27
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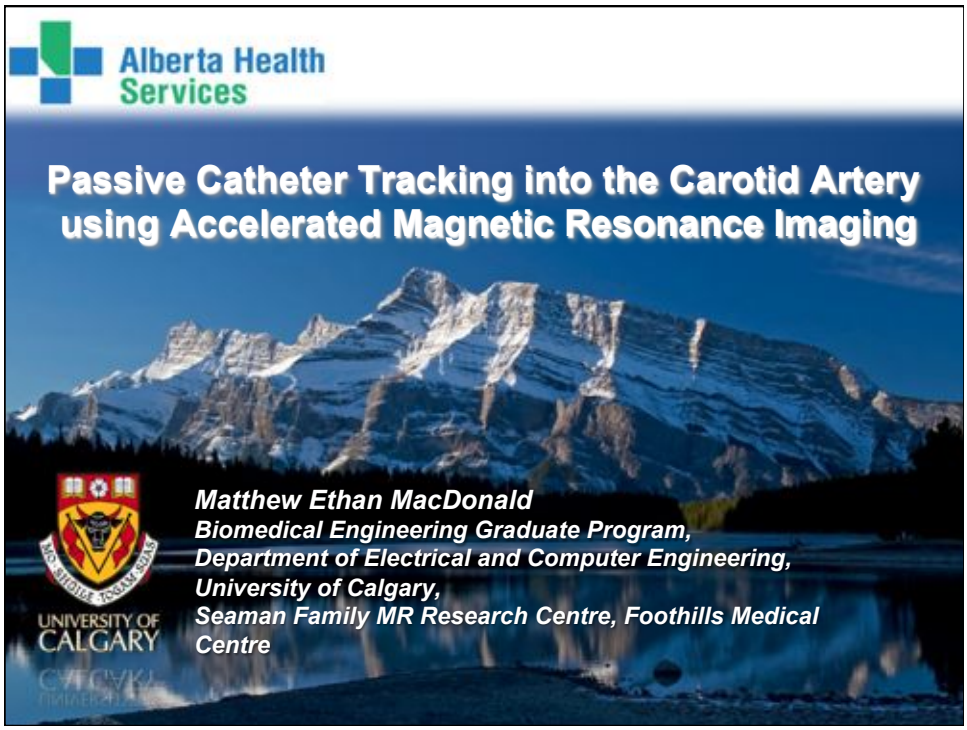
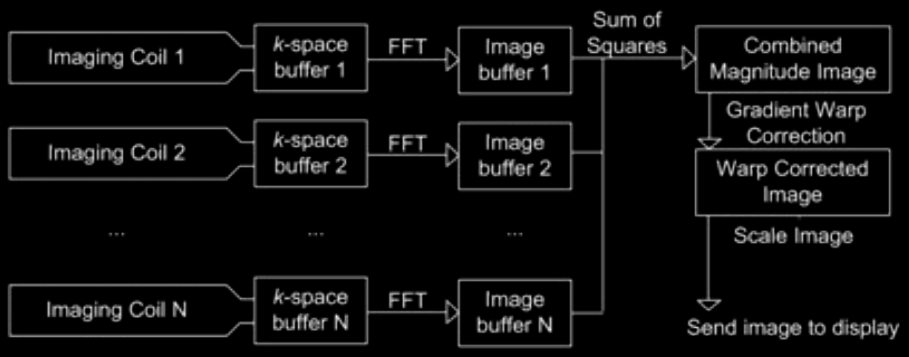

Alberta Health Services
Passive Catheter Tracking into the Carotid Artery using Accelerated Magnetic Resonance Imaging
UNIVERSITY OF CALGARY
Matthew Ethan MacDonald
Biomedical Engineering Graduate Program,
Department of Electrical and Computer Engineering,
University of Calgary,
Seaman Family MR Research Centre, Foothills Medical Centre

Real Time MR Imaging Platform



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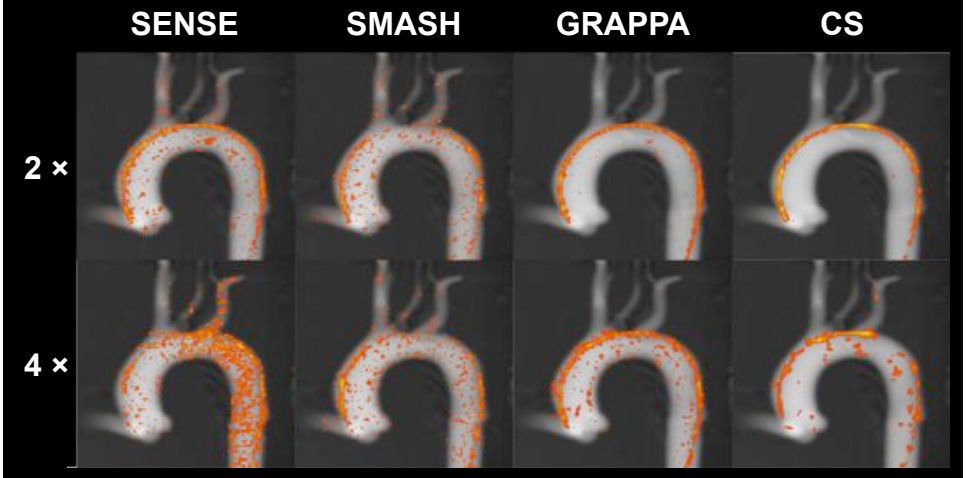
In Vitro Acceleration



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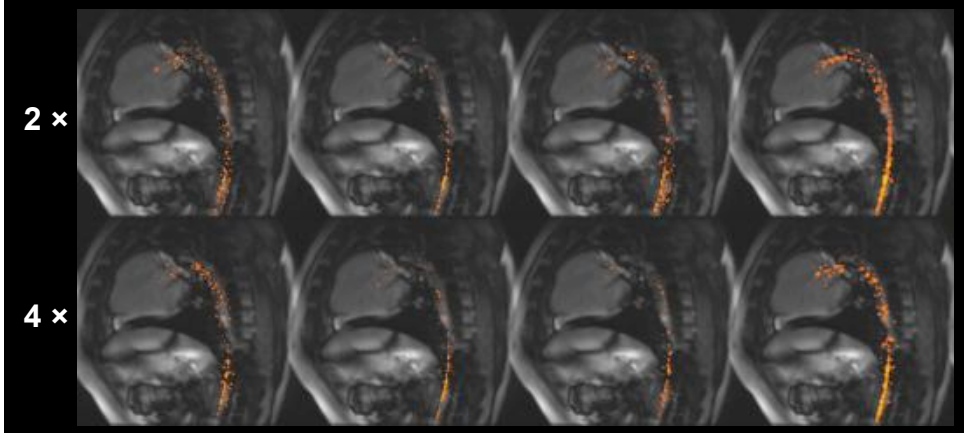
In Vivo Acceleration



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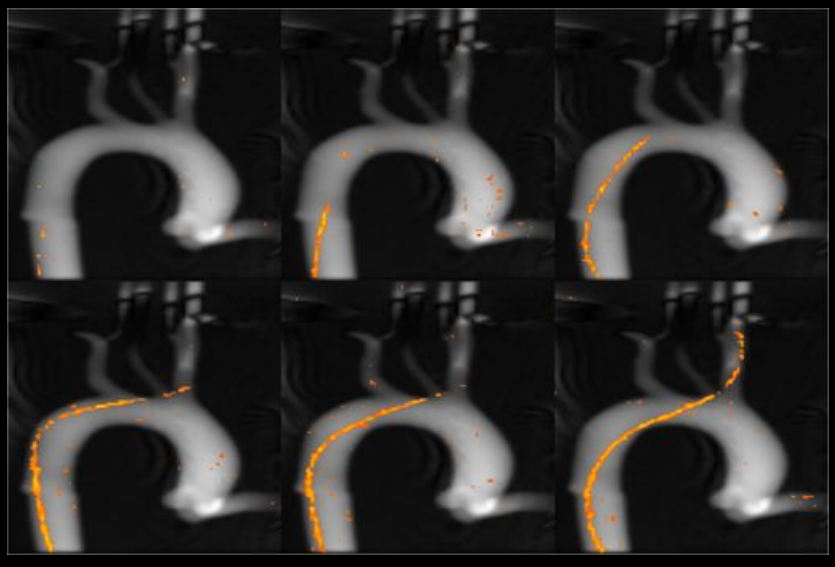
In Vitro Tracking



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Alberta Health Services

WiP

Visualizing Small Intracranial Arteries using TOF with Compressed Sensing

J Yerly, ML Lauzon, R Frayne
Electrical and Computer Engineering, Radiology and Clinical Neurosciences, University of Calgary, and Seaman Family Centre, Foothills Medical Centre

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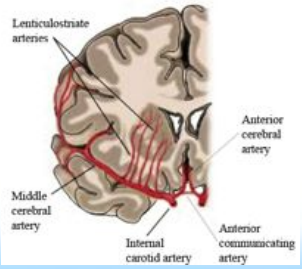
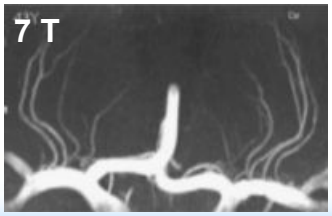
Small Intracranial Arteries

- Lenticulostriate arteries
- Diameter: 100 µm to 900 µm
- Lacunar strokes
- Challenging to visualize with ≤3 T scanner



Purves *et al.* Neuroscience 2001; Figure 1.20



Kang *et al.* Int J Stroke 2010;5:374

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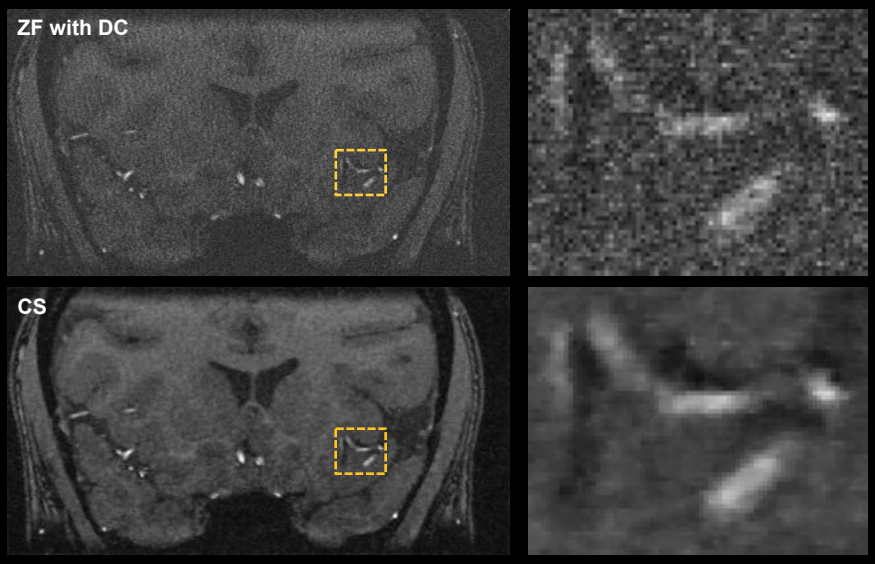
MR Angiogrpahy - Source Images



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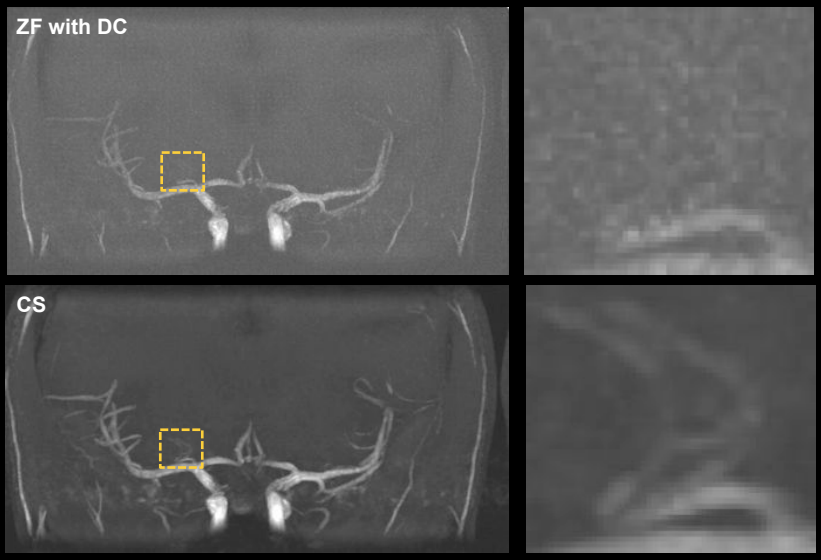
Maximum Intensity Projection Images



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Summary

- Lots of work left to do…
- Preliminary *in vitro* and *in vivo* studies look promising
- CS may be able to reconstruct accurate images if sparsity condition is met
- Need to
  - better understand errors in images, and
  - speed up reconstruction

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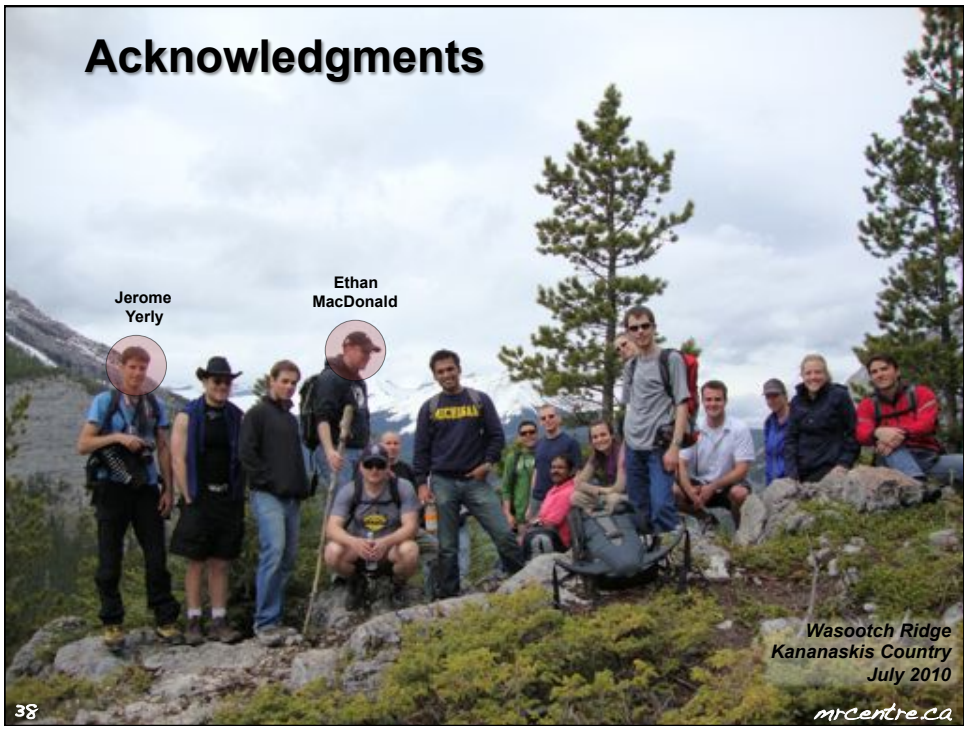
Acknowledgments



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Acknowledgments
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Alberta
Freedom To Create. Spirit To Achieve.
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