Diffusion Tensor Imaging (DTI)

for the study of disorders of consciousness

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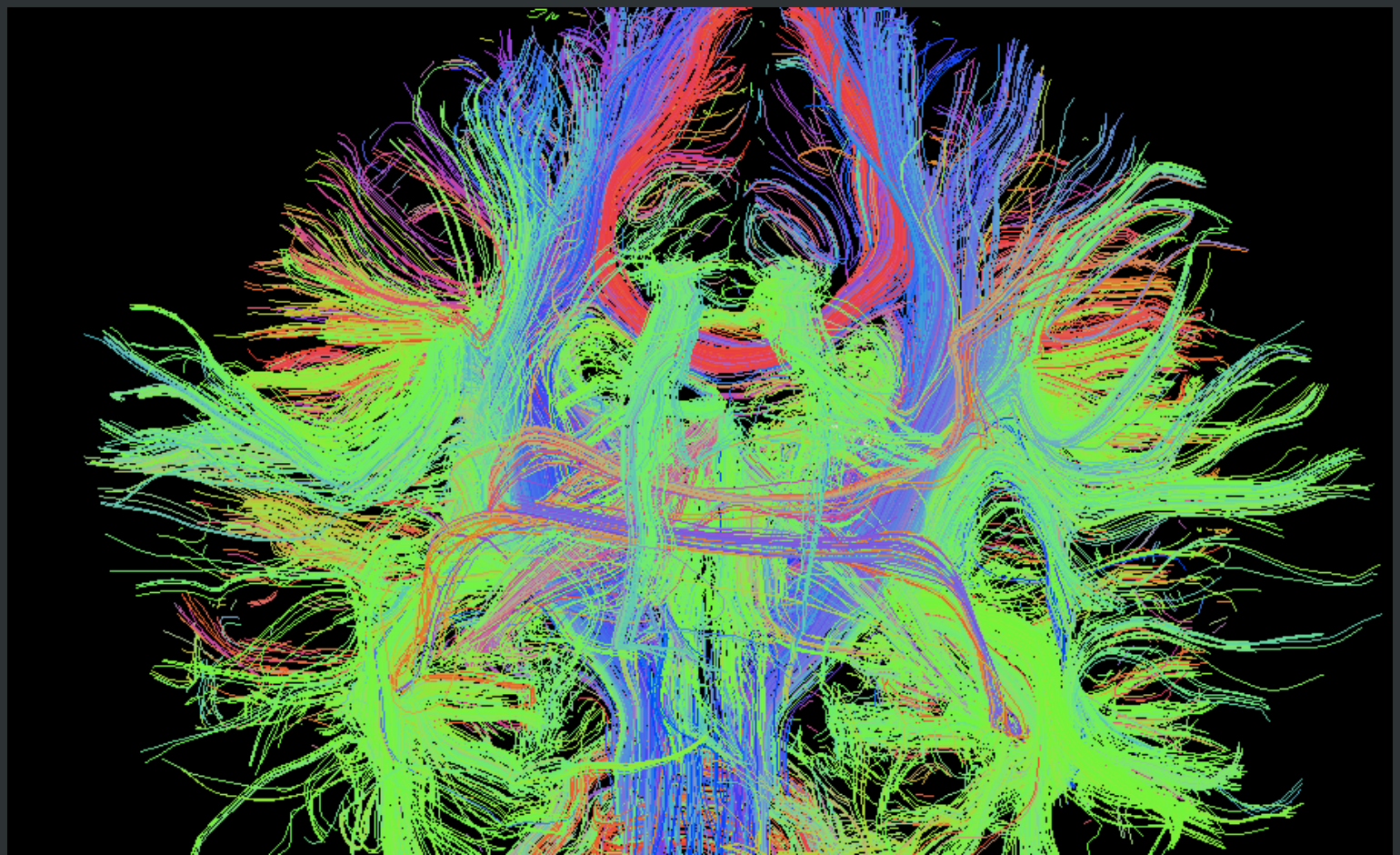
24/03/2017

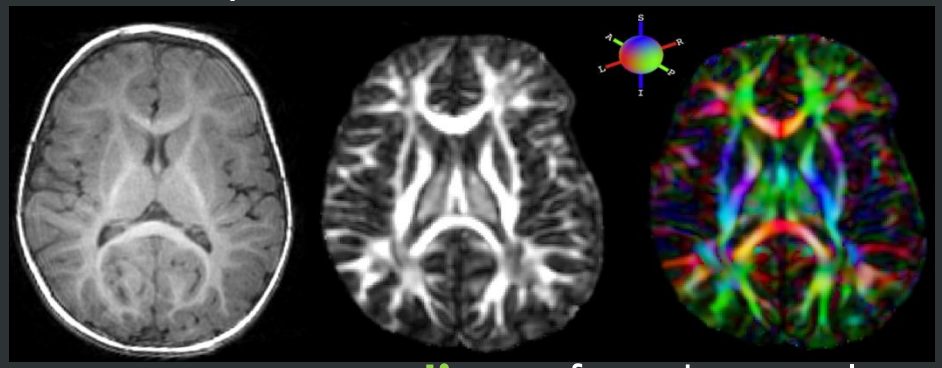
Motivation

- Connectivity is of paramount importance for consciousness
- Study **connectivity structure** (micro and macro) from **white matter**

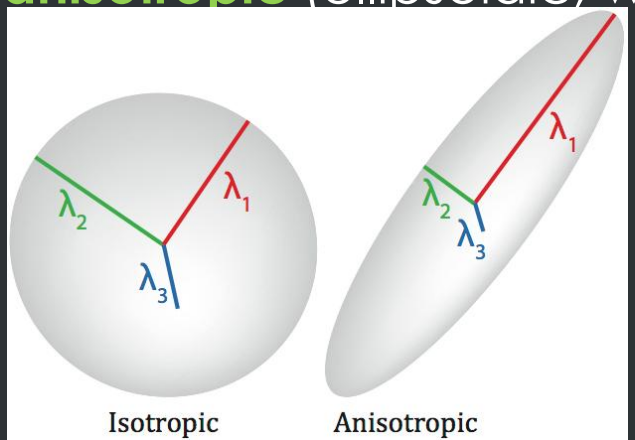


DTI preproc in 3 easy steps! (sort of…)

1. Using diffusion magnetic resonance imagery, **acquire water** molecules (brownian) **motion**.



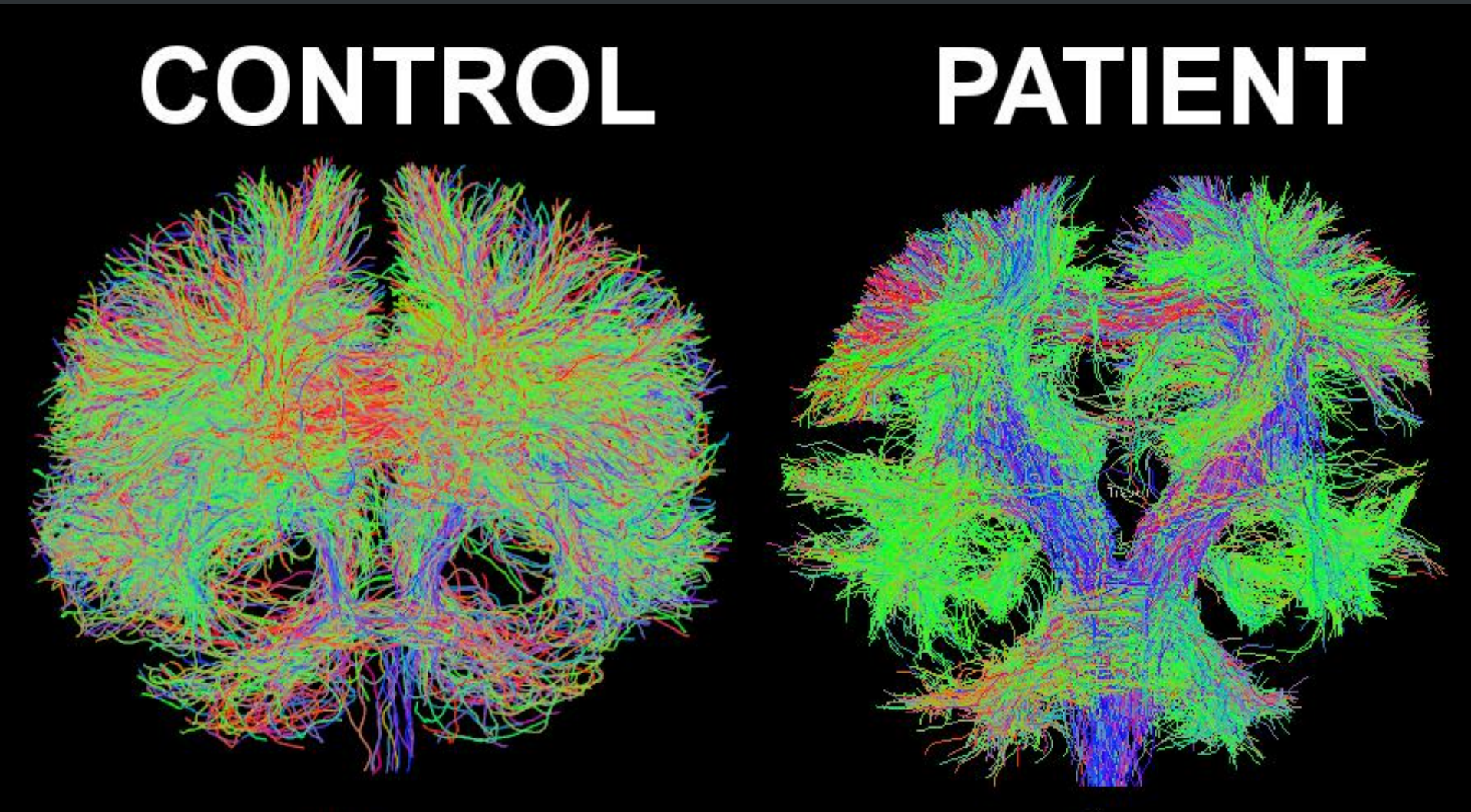
2. Estimate **tensors** ≈ **mean motion** of water molecules for each brain's voxel. We get isotropic (round, grey matter) and **anisotropic** (ellipsoidic, white matter) shapes.



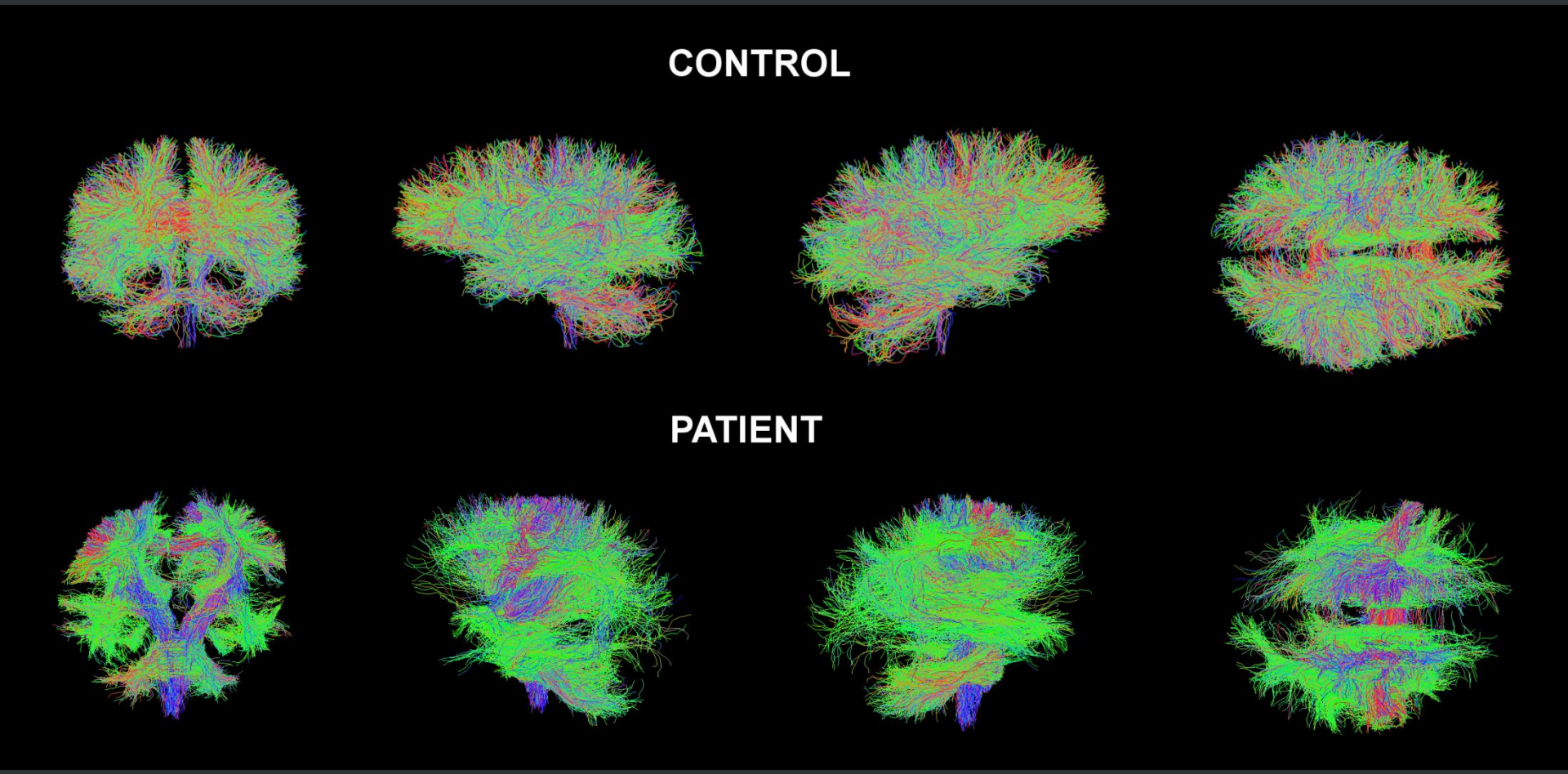
DTI preproc in 3 easy steps! (sort of…)

3. Estimate **tractography** (=**connectivity map**): use a **probabilistic** algorithm (Viterbi) to walk through the tensors and reconstruct a brain connectivity map.

Result



Result



DTI preprocessing theory vs reality

DTI preprocessing summary **in theory**:

1. Acquire DTI images (= hydrogen particles motion)
2. Estimate tensors (= mean particles motion)
3. Tractography (= reconstruct tracts and disambiguate cross-sections)

DTI preprocessing theory vs reality

DTI preprocessing summary **in practice**:

1. Acquire DTI images + T1
2. Reorient both
3. Extract gradients (bvecs and bvals)
4. Brain Extraction (BET) mask on DWI and T1
5. Correct eddy currents
6. Estimate tensors & FA metrics
7. Segment T1
8. Coregister DWI on T1
9. Downsample T1
10. Estimate DWI response function
11. Tractography
12. And more steps depending on your objectives…

→DTI is still in the process of standardization… but not there yet!

2nd-level analysis (group comparison)

- **Fixel-based (local metrics) approach:**
  1. Normalize all subjects on a (tracts) template
  2. Compare **locally** difference of tracts metrics (eg, AFD for density)

  Advantage: compare directly the whole structure, but at the expense of losing info at normalization.
- **Connectome approach:**
  1. **Parcellation** (Freesurfer) to get regions (or use map provided in MRTRIX)
  2. Connectivity matrix (tck2connectome)
  3. Graph theory measures and comparison

  Advantage: respects each subject's structure and global brain approach, but lose info at parcellation (your analysis is as good as your parcellation)
- **Average/global measures approach:**
  1. Compute a global measure for each subject (eg, average FA)
  2. T-test on the values of one group with the other group

Take home message

- Enables research of **connectivity** fibers' **micro-** and **macro-structure**
- **In vivo** (and the first one!)
- By measuring the magnitude and orientation of water diffusion

-> non-invasive

- Useful pre-clinical **diagnosis** tool
- Limitation: only ~30% of DTI fibers actually exist in the brain, keep in mind it's a model!

To go further

- MRTRIX3 whole documentation
- Beginner's DTI preprocessing pipeline (up to connectome analysis): http://community.mrtrix.org/t/beginner-connectome-pipeline-updated/373/2
- Fixel-based analysis using MRTRIX3: http://mrtrix.readthedocs.io/en/latest/workflows/fixel_based_analysis.html
- Connectome analysis using MRTRIX3 (tck2connectome): http://mrtrix.readthedocs.io/en/latest/workflows/structural_connectome.html http://community.mrtrix.org/t/the-output-of-tck2connectome/345
- Global measure analysis: see afdconnectivity and http://mrtrix.readthedocs.io/en/latest/workflows/DWI_preprocessing_for_quantitative_analysis.html
- FSL eddy (eddy currents + motion/realignment correction)
- Subparcellation
- Do Tromp's DTI tutorials, **diffusion-imaging.com**, 2016
- MRTRIX3 community forum! community.mrtrix.com

Thank you for your attention

References:

•**Posterior cingulate cortex-related co-activation patterns: a resting state FMRI study in propofol-induced loss of consciousness**, Amico, Enrico, et al, *PLoS One* 9.6 (2014): e100012.

•**Multimodal neuroimaging in patients with disorders of consciousness showing "functional hemispherectomy"**, Van Someren, E. J. W. (2011), *Slow Brain Oscillations of Sleep, Resting State and Vigilance: Proceedings of the 26th International Summer School of Brain Research, Held at the Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands, 29 June-2 July, 2010*, *193*, 323.

• **Neural correlates of consciousness in patients who have emerged from a minimally conscious state: a cross-sectional multimodal imaging study**, Carol Di Perri & Mohamed Ali Bahri & Enrico Amico & Aurore Thibaut & Lizette Heine et al., The Lancet Neurology, 2016

•Do Tromp, **http://www.diffusion-imaging.com/,** 2016

•Amico et al., Conf Proc IEEE Eng Med Biol Soc. 2015

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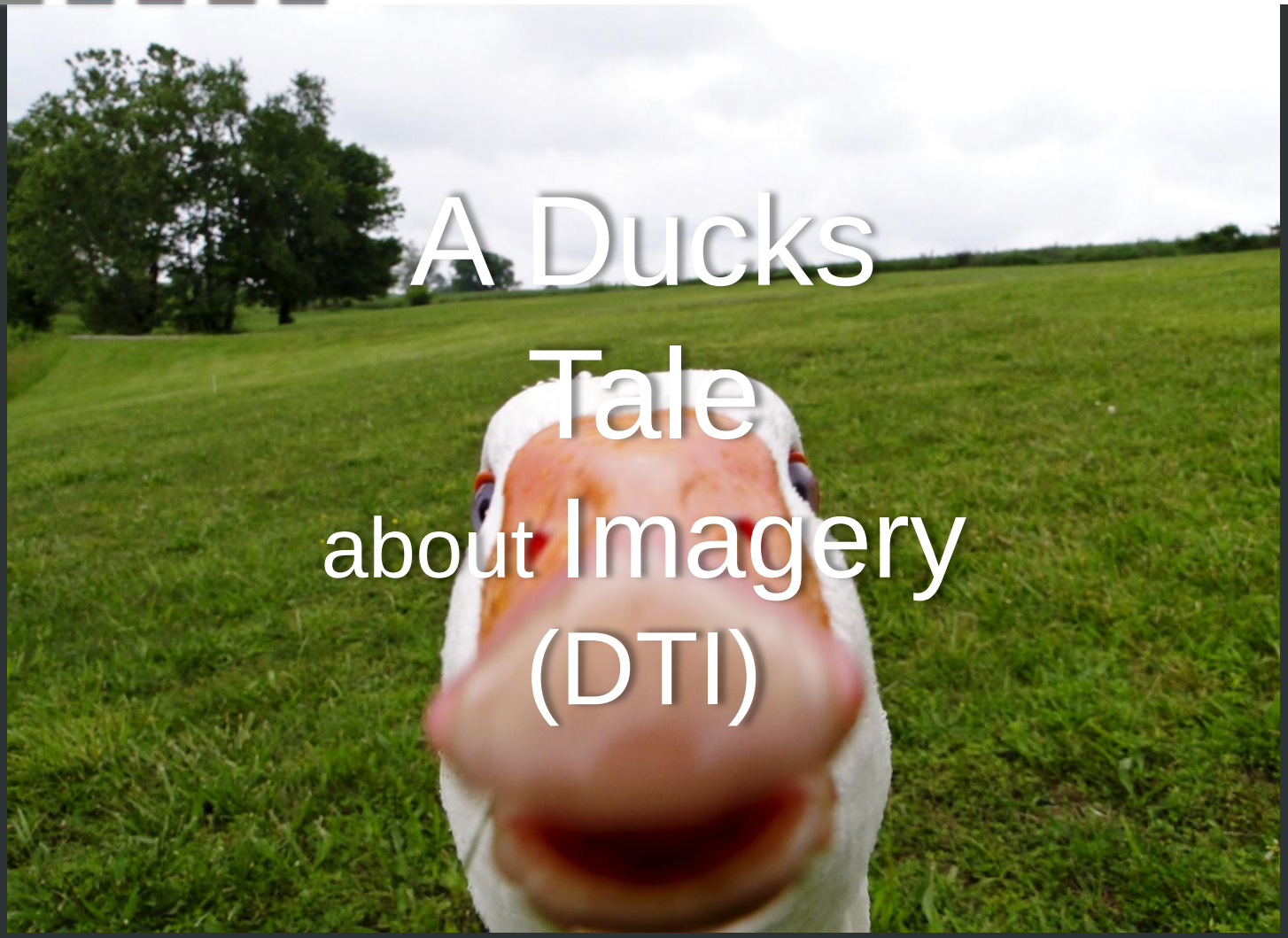
BONUS SLIDES

How DTI works – A small tale



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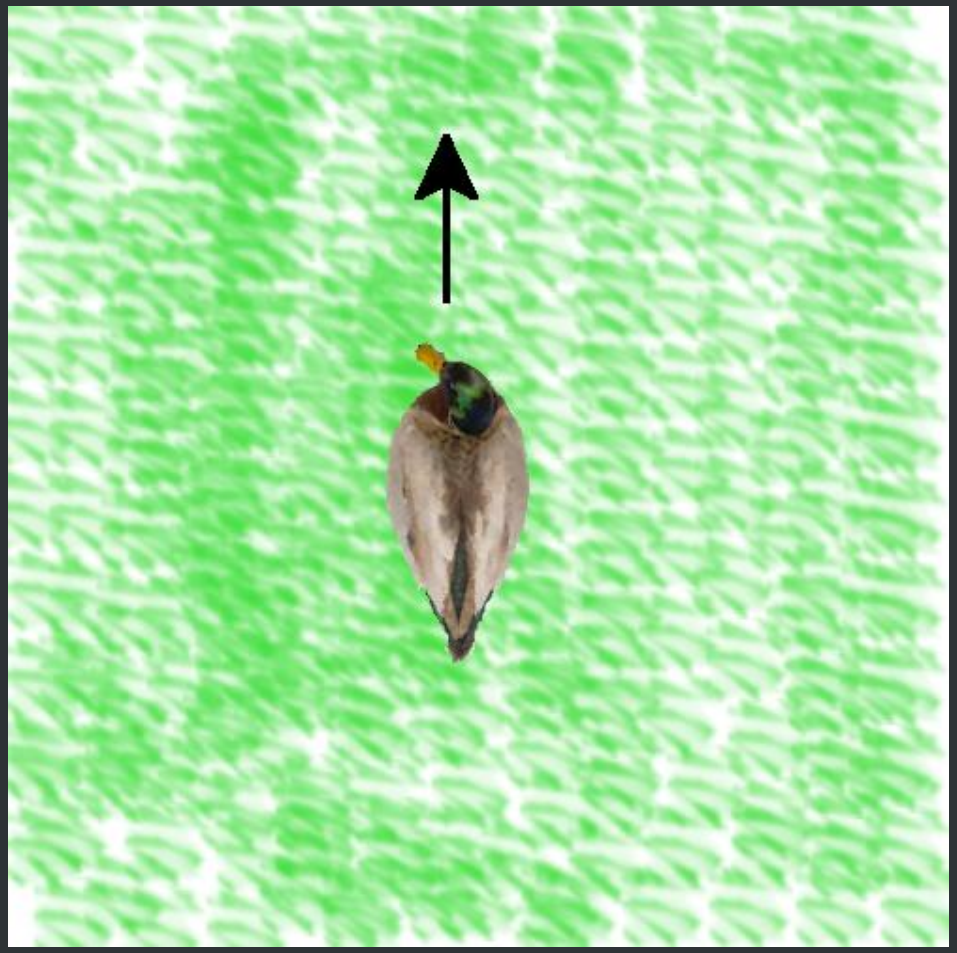

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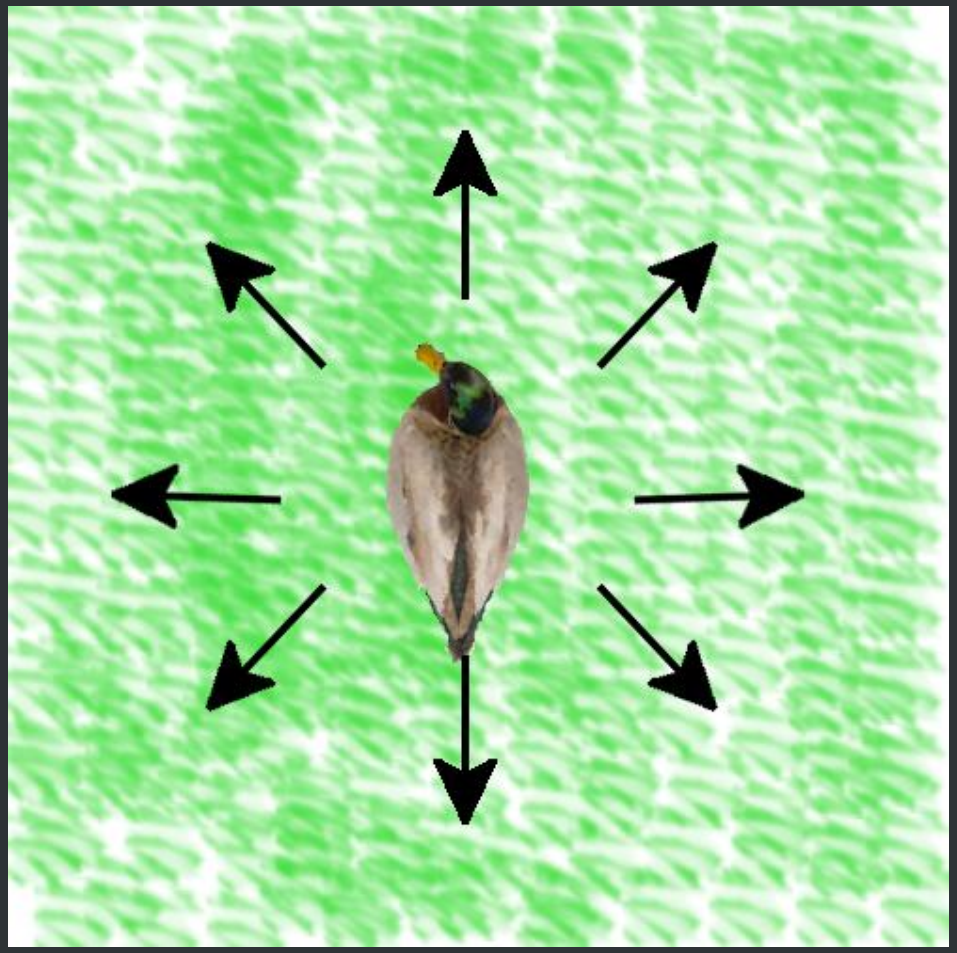

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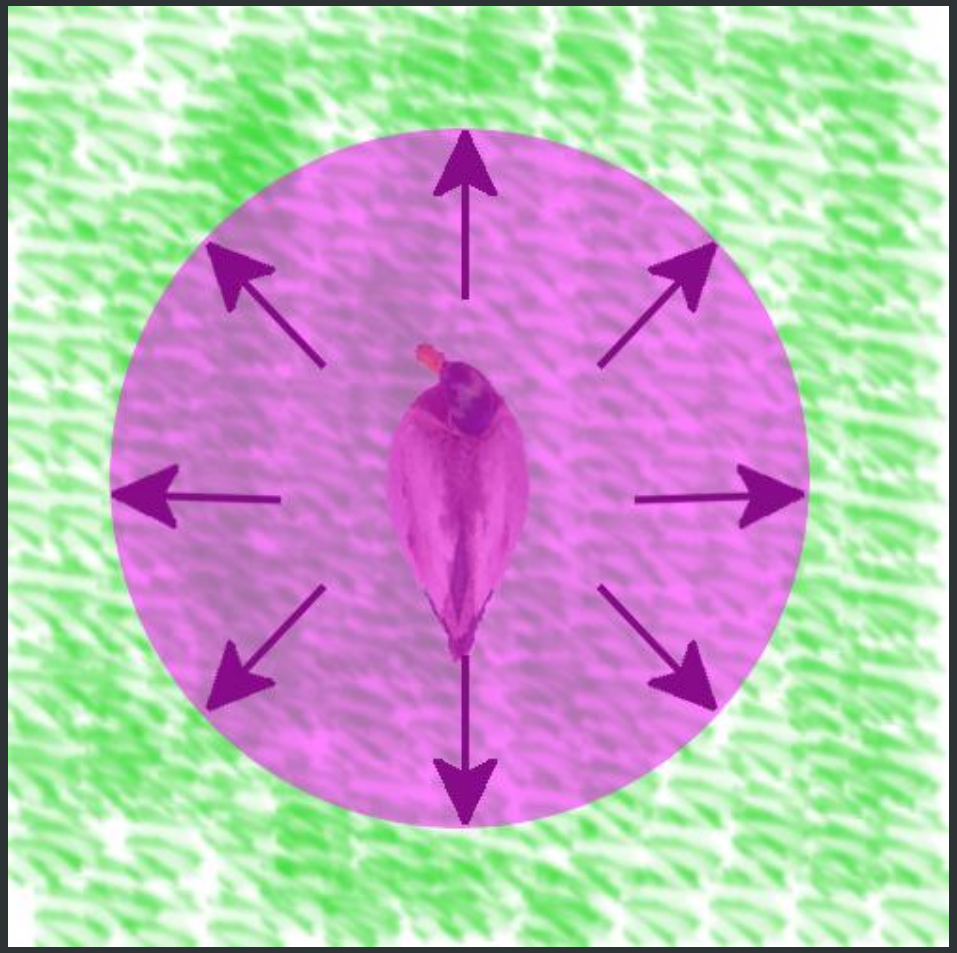

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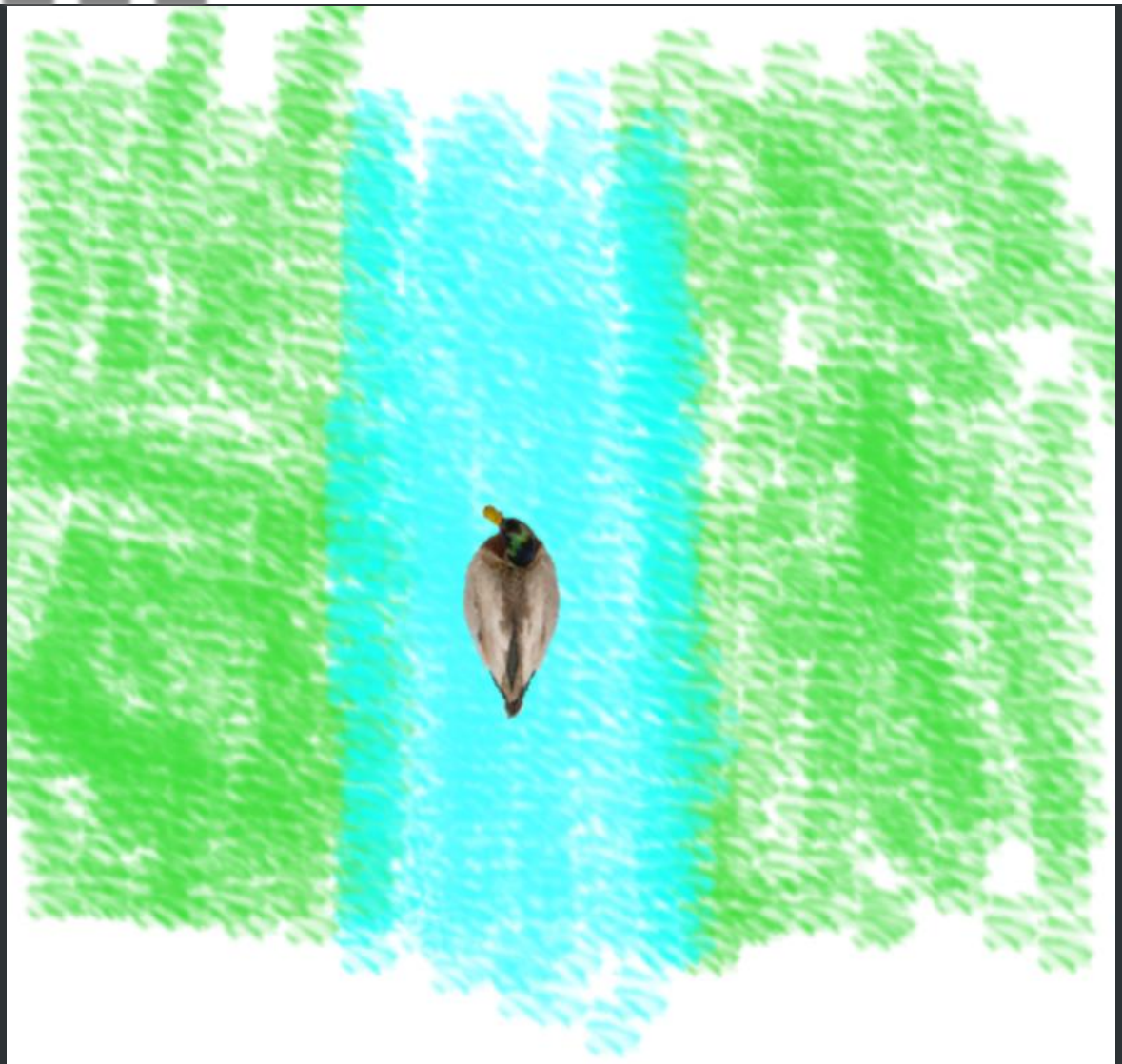

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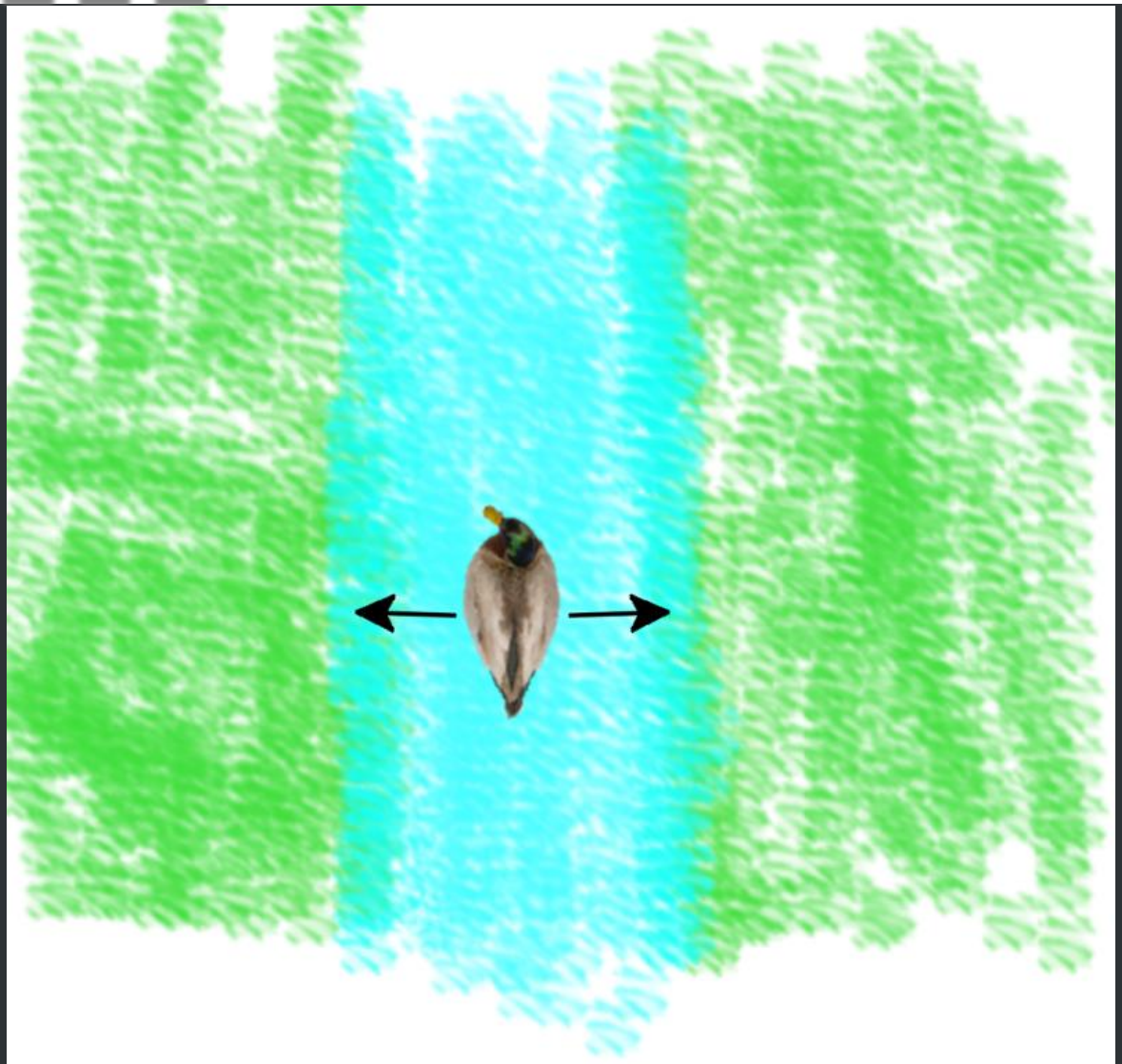

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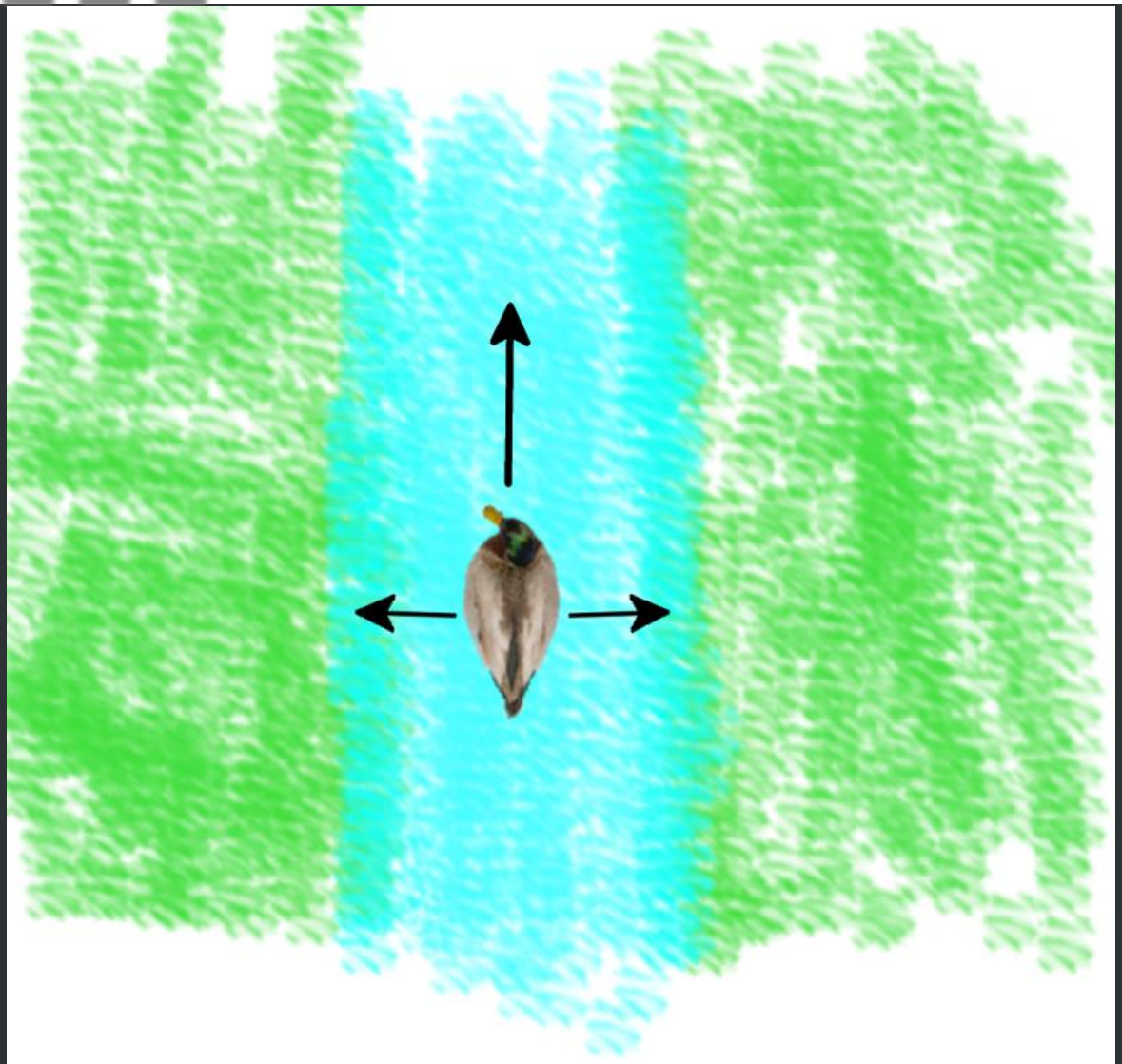

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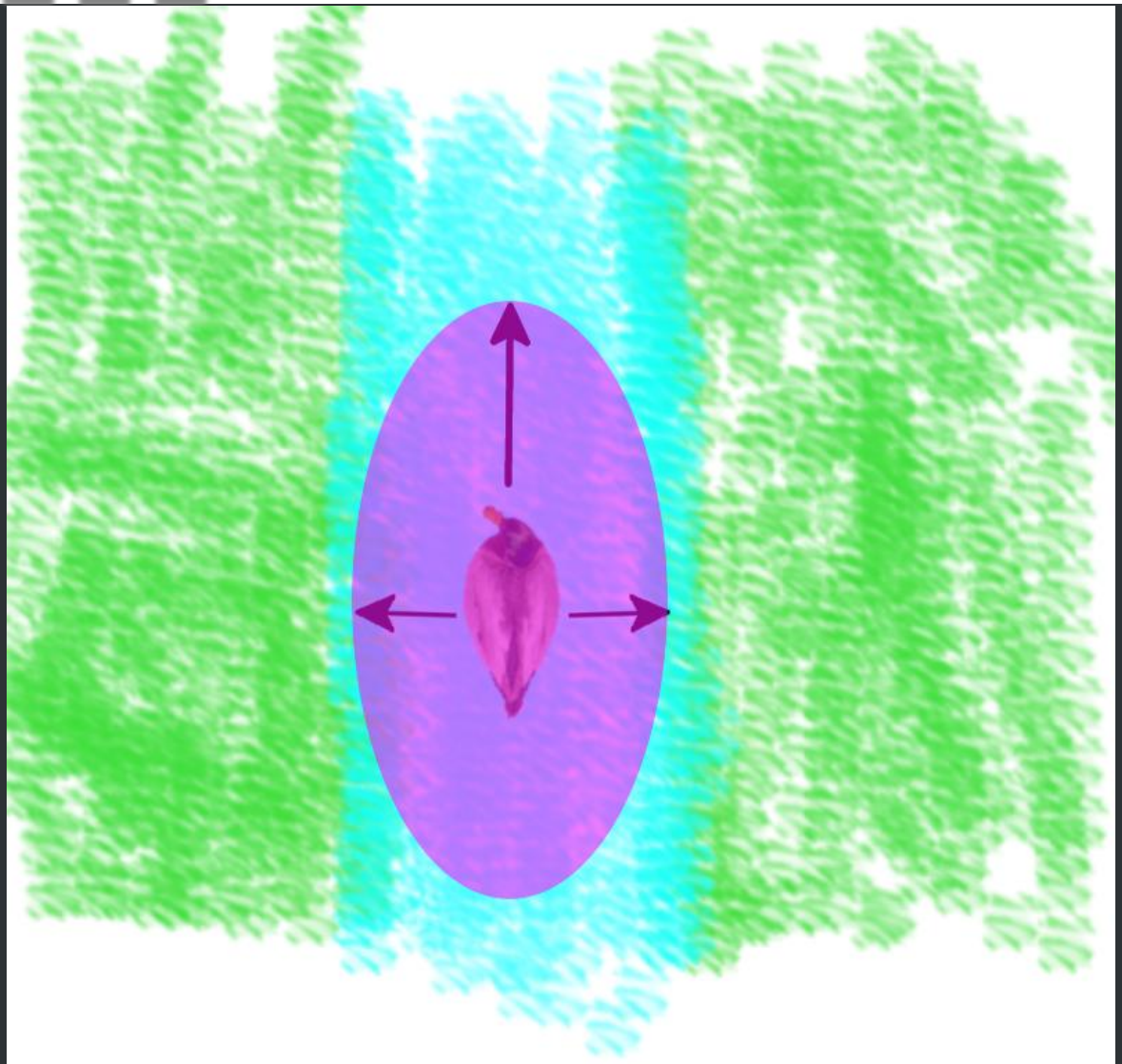

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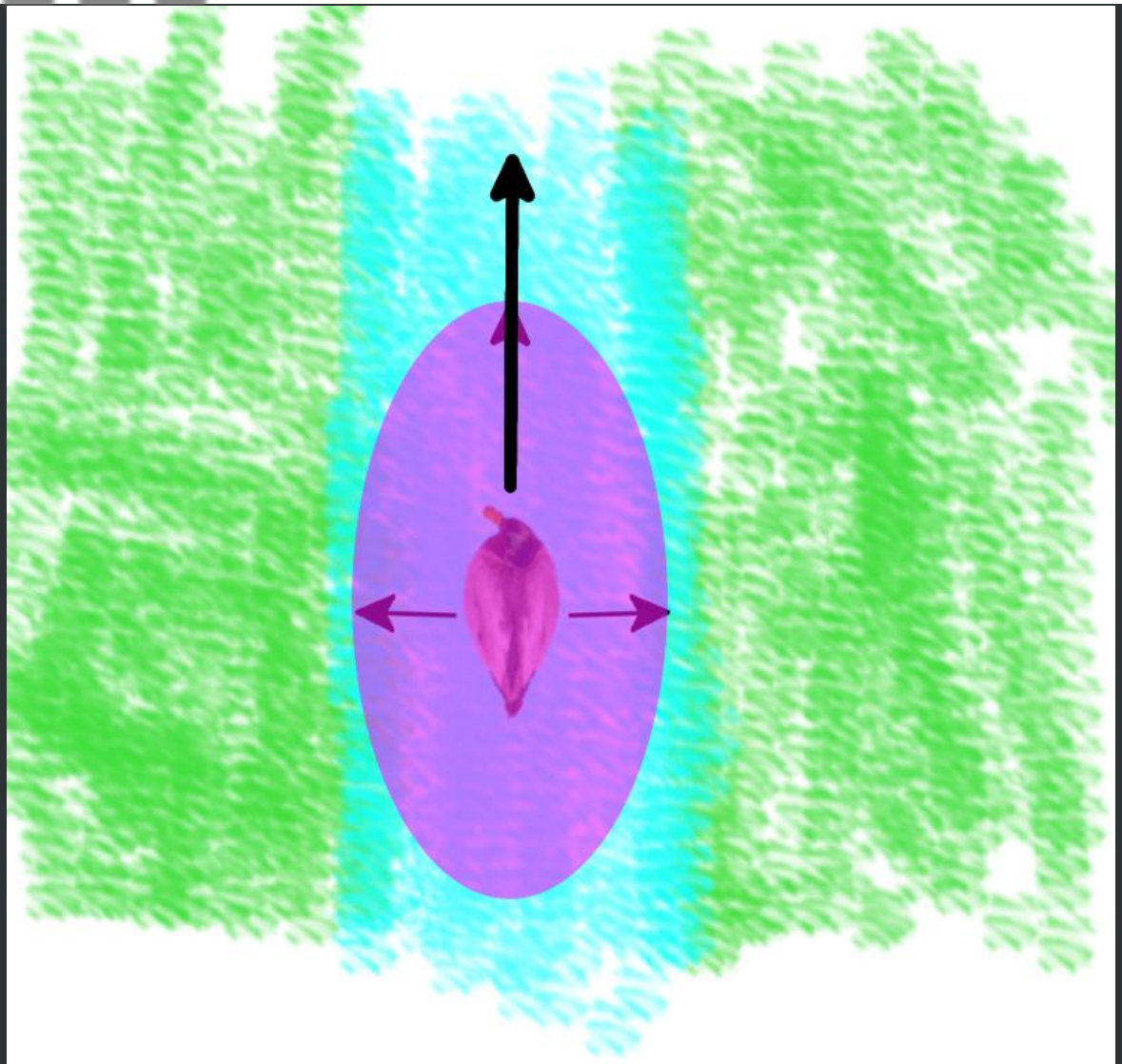

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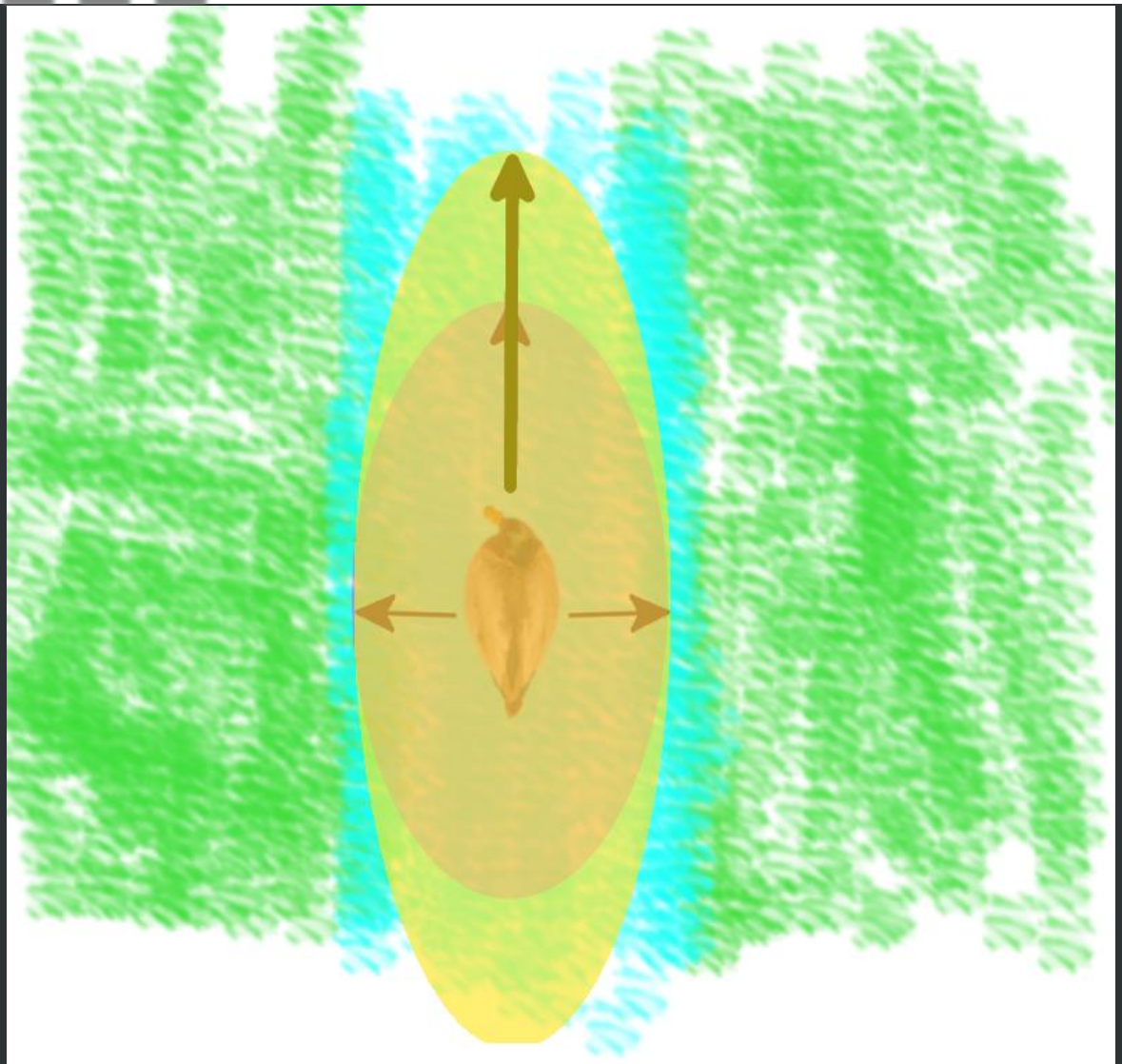
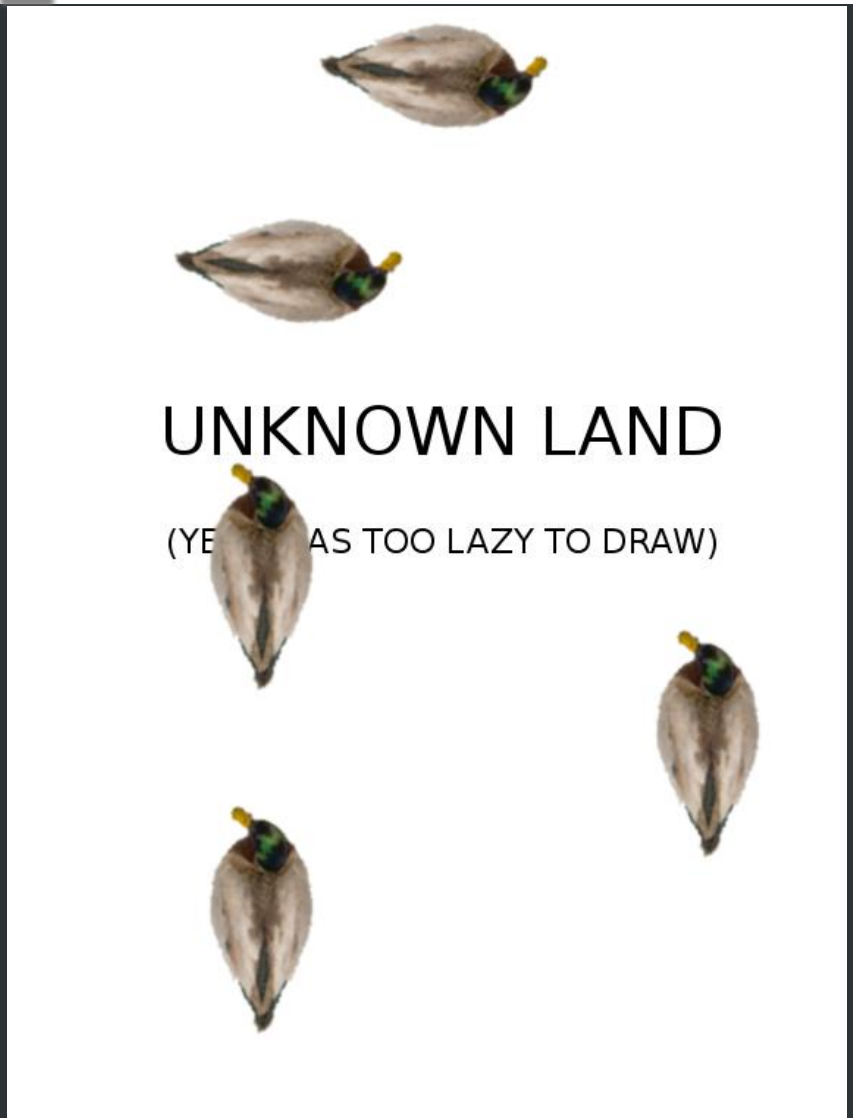


How DTI works – A small tale

UNKNOWN LAND

(YES I WAS TOO LAZY TO DRAW)

How DTI works – A small tale



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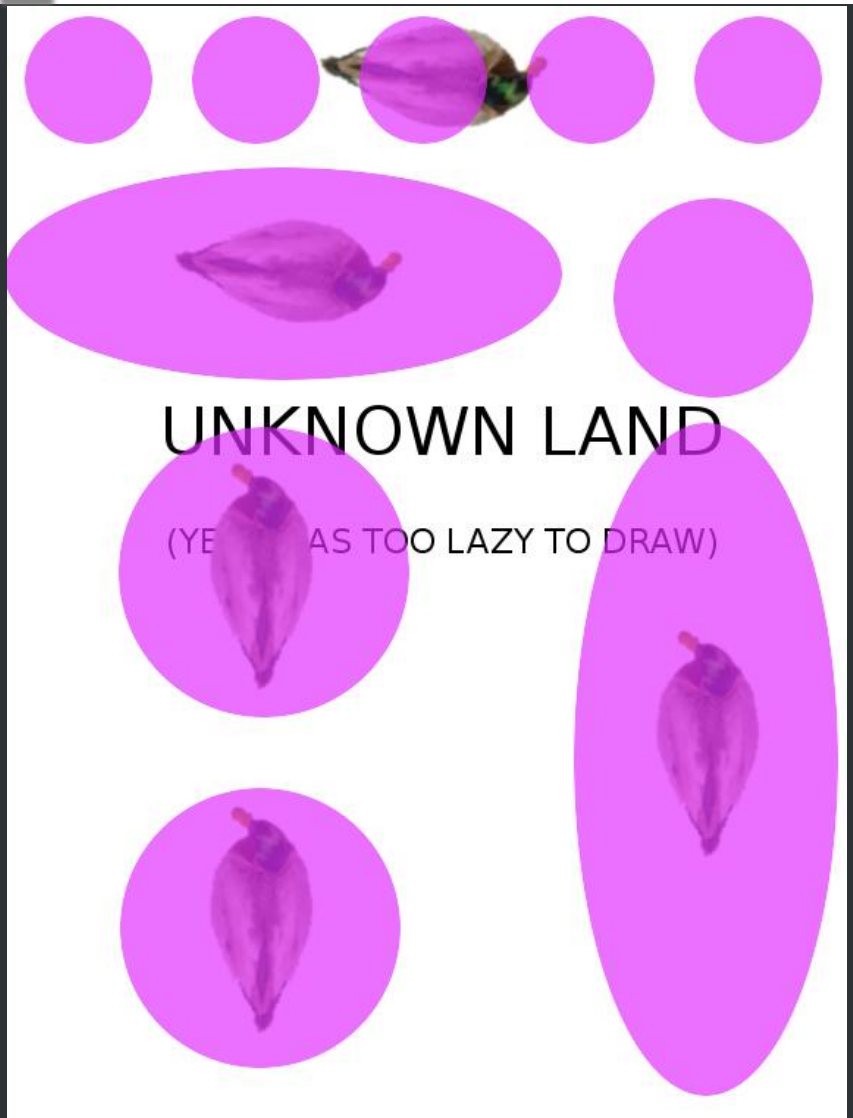

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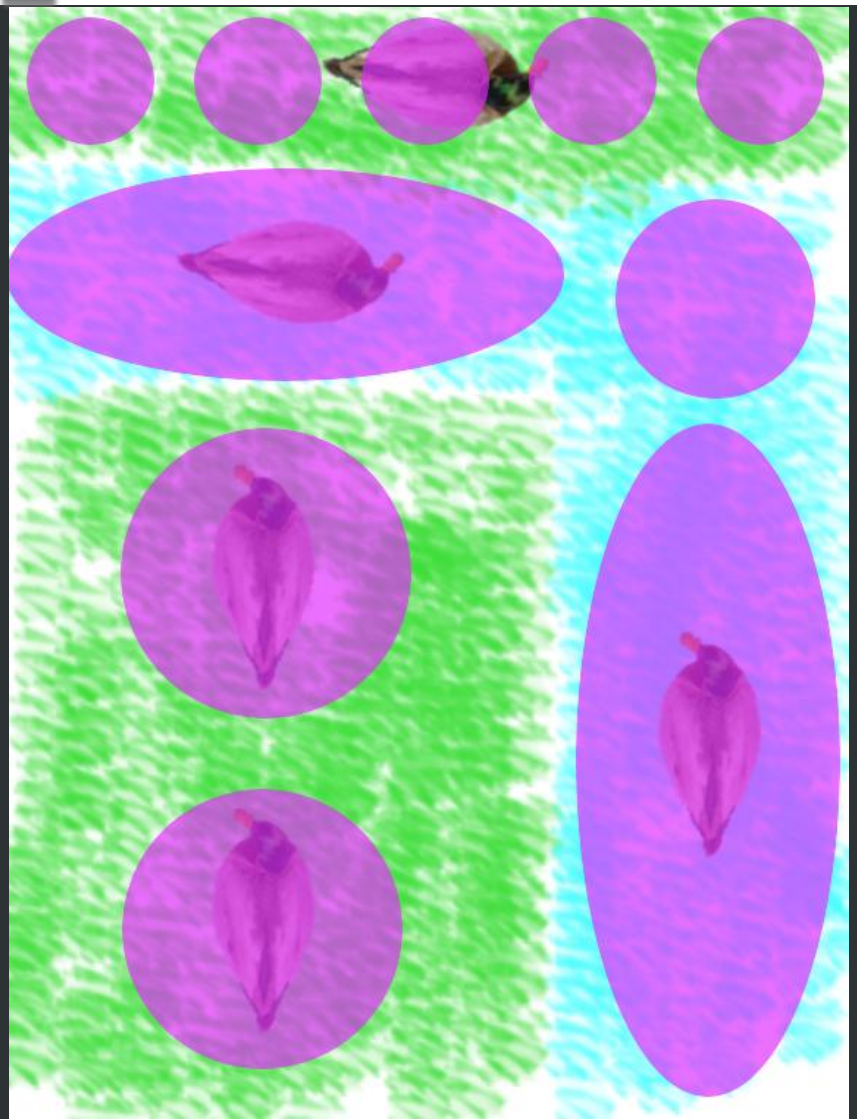

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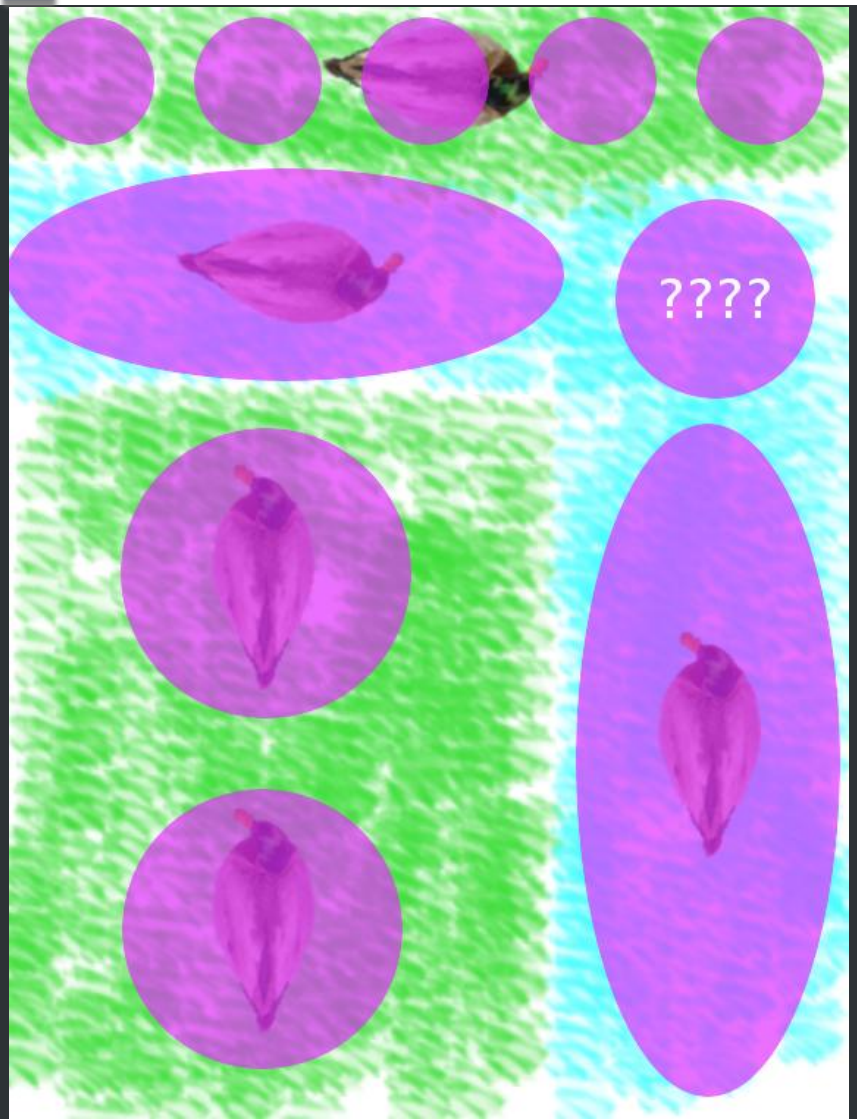

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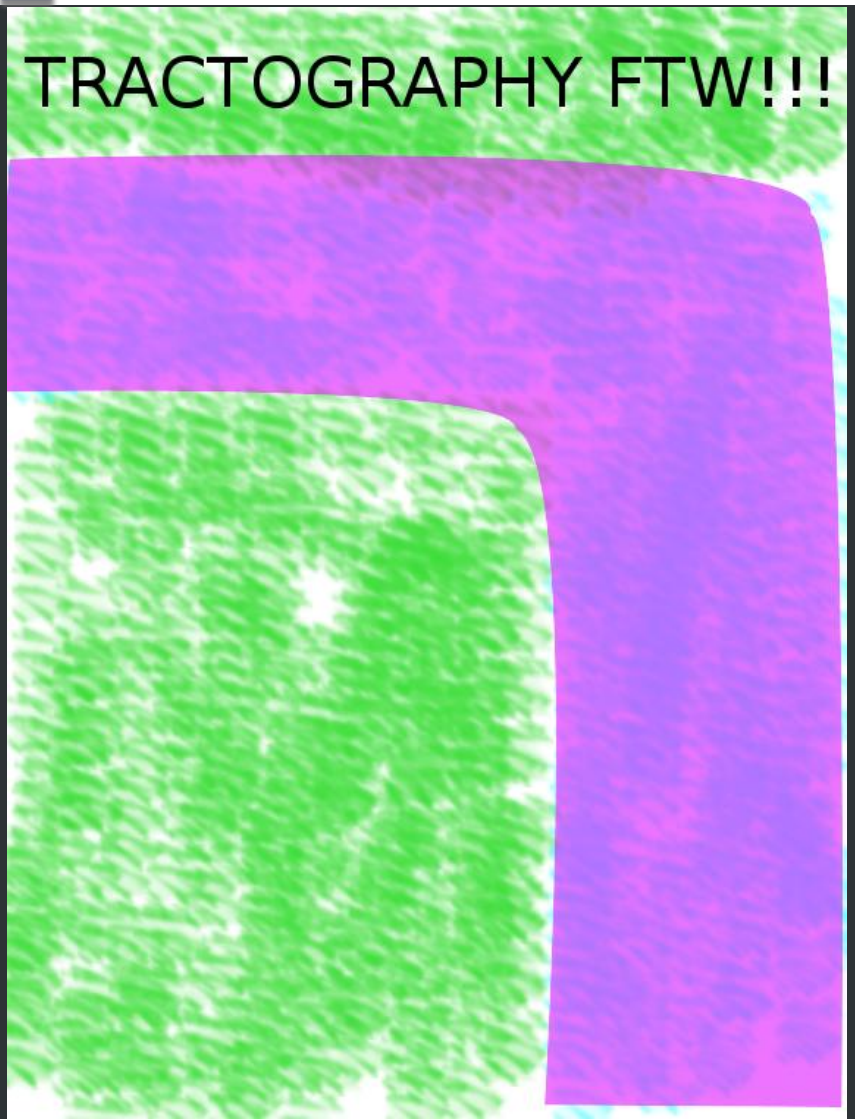

Duck's tale imagery to DTI

- Ducks with GPS = **hydrogen** particles (in water molecules)
- Ducks motion = **Brownian** motion (influenced by environment)
- Ellipsoid of average travel distance = **FA tensors** (Fraction Anisotropy)
- Rivers = white matter **fibers tracts**
- Solving river cross-sections = **tractography**