

Motion-Compensated Neuroanatomical Imaging

Dylan Tisdall
October 5, 2010

Motion-compensated MRI sequences allow you to image subjects even if they move, without discarding scans and rescanning.

Who should use these sequences? Everyone!

- Our sequences are available now on Siemens scanners.
- Other groups are developing similar techniques on GE scanners.

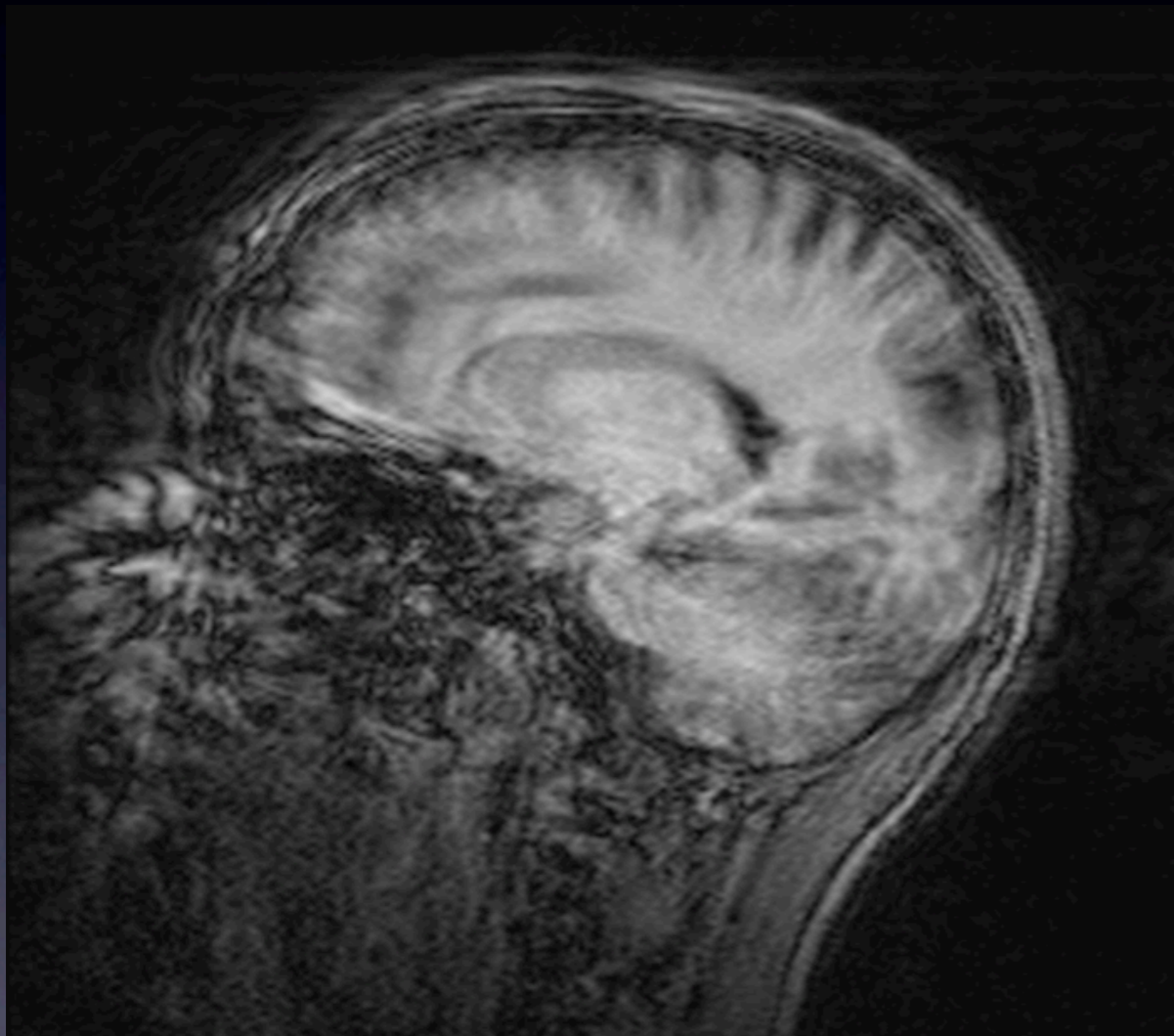
Overview

- **Following the subject:**
EPI-navigated prospective motion correction
- **More motion-resistance:**
automatic retrospective reacquisition
- **Differences from regular scans:**
contrast, scanner availability, usage notes

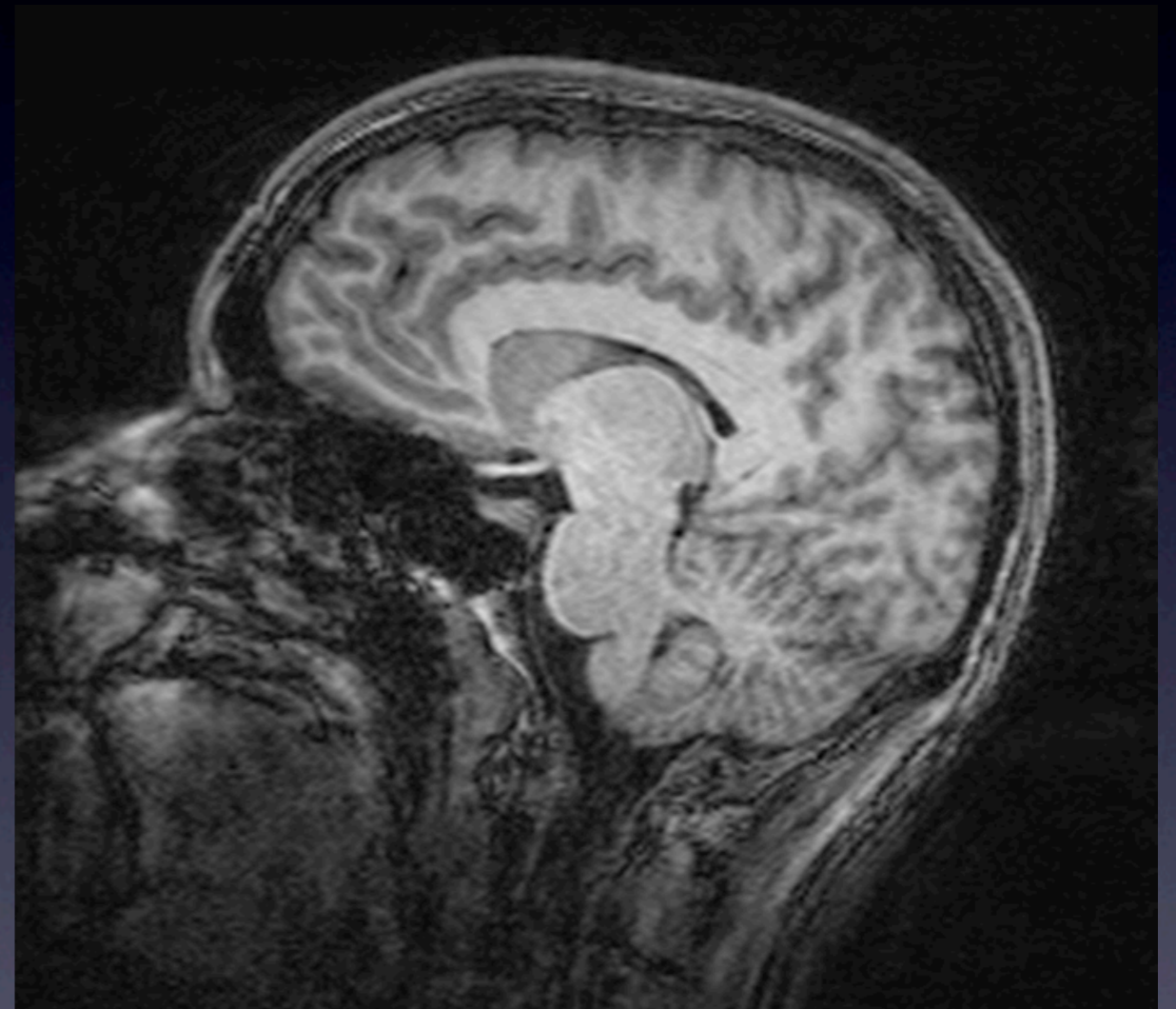
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MPRAGE of subject prompted to
change position every 45 seconds.

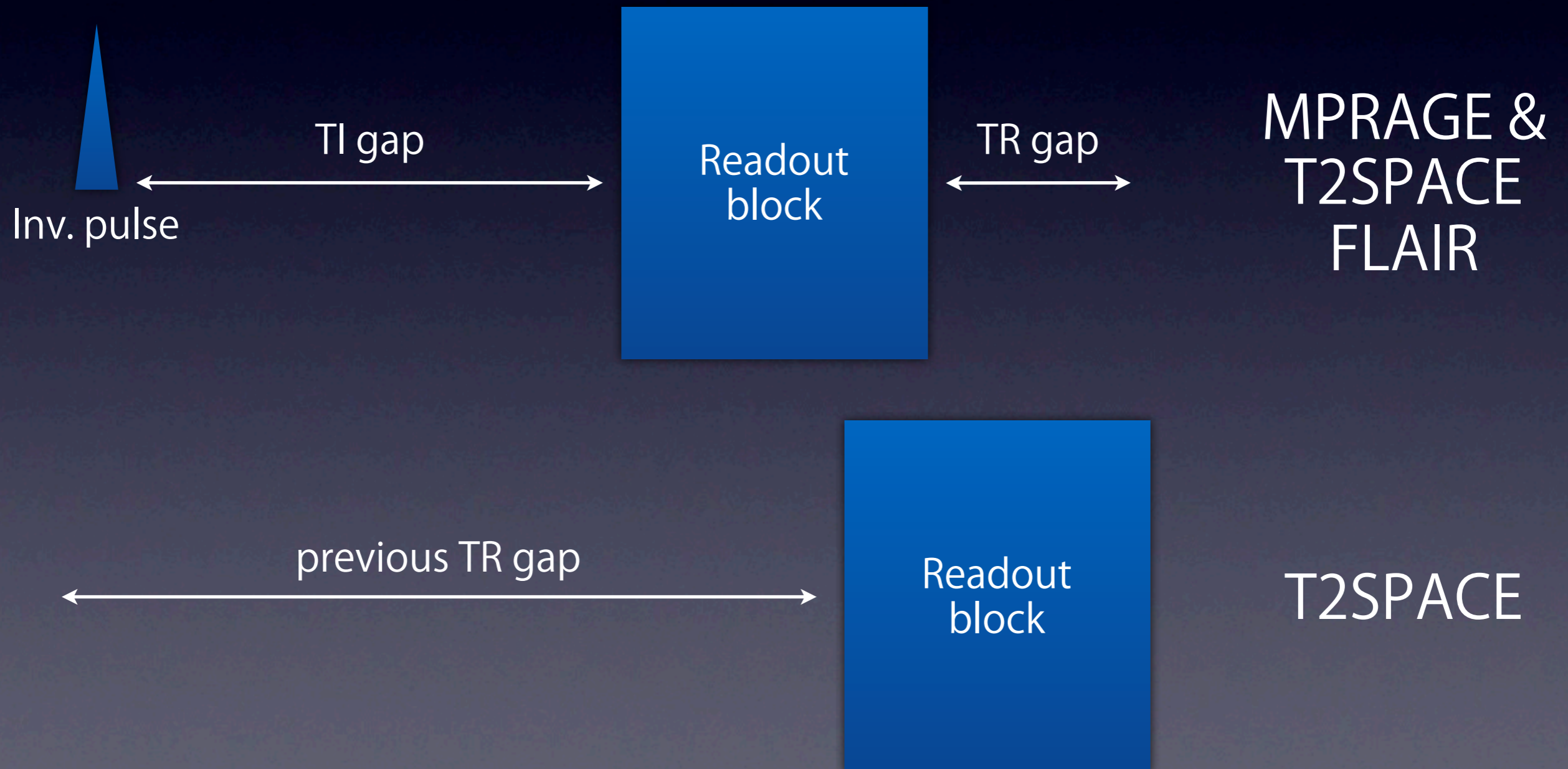


without prospective moco

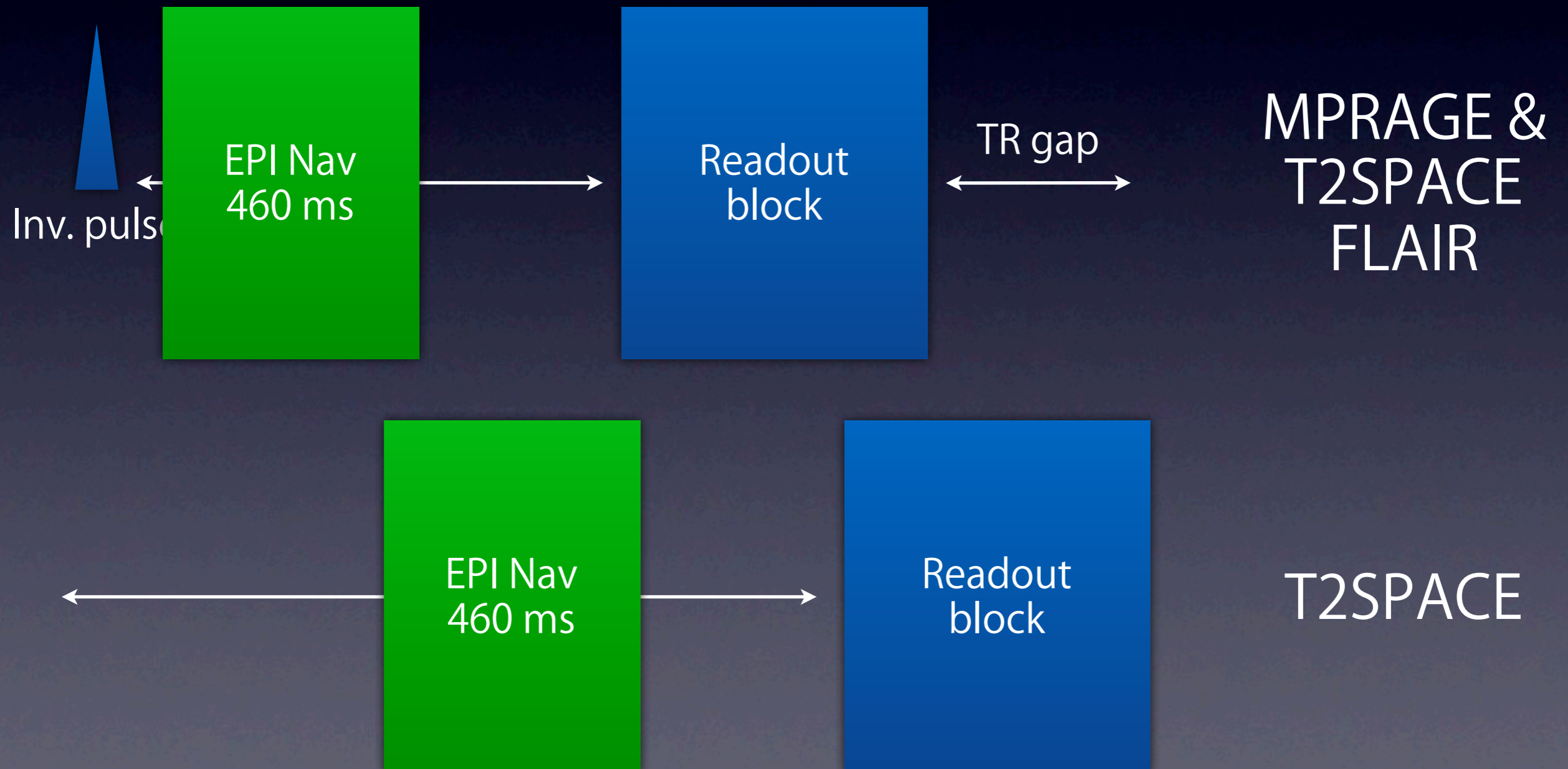


with prospective moco

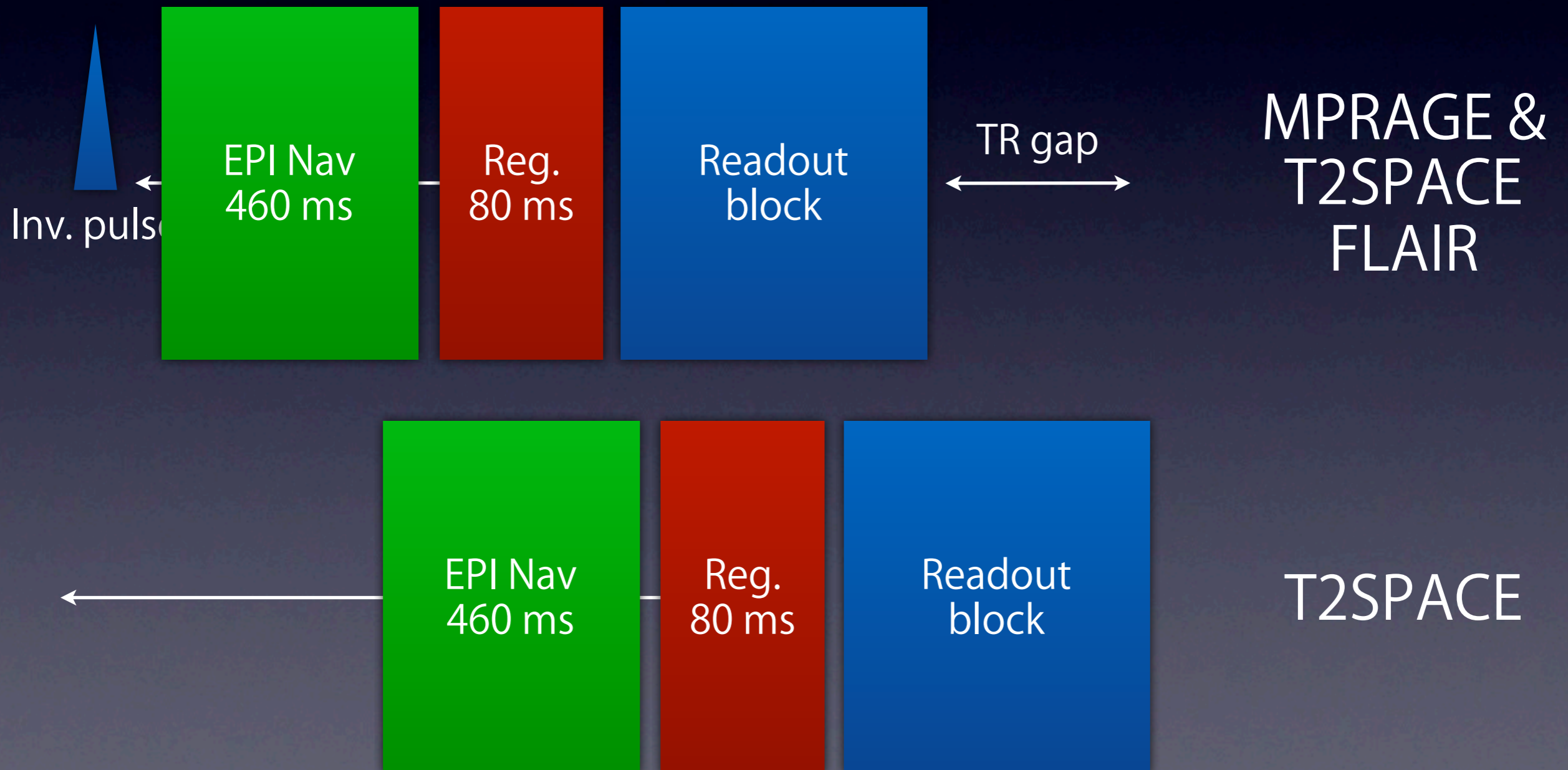
A single TR



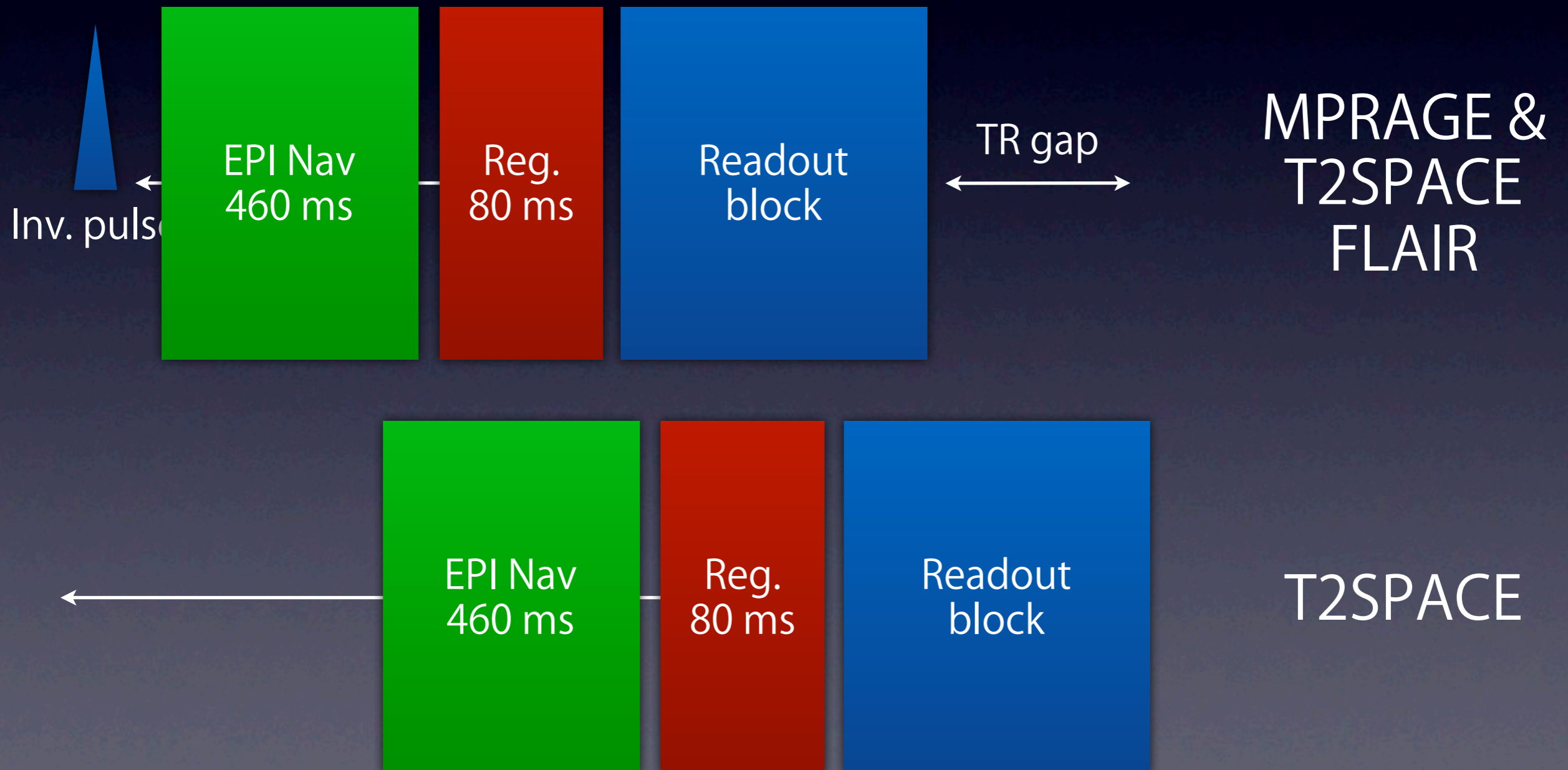
A single TR + EPI Navigator



A single TR
+ EPI Navigator
+ Registration and Feedback

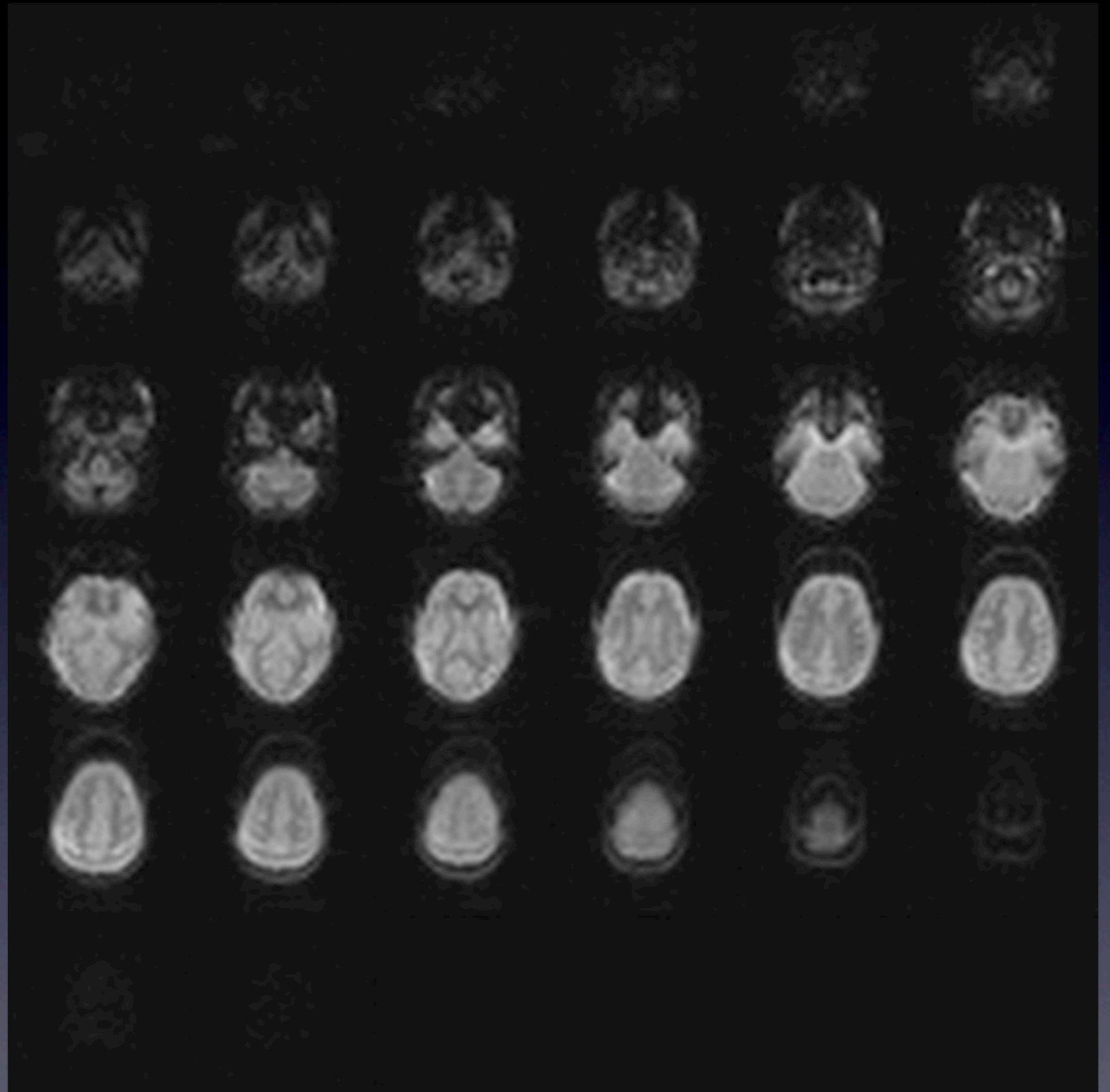


A single TR
+ EPI Navigator
+ Registration and Feedback
= updated imaging coordinates

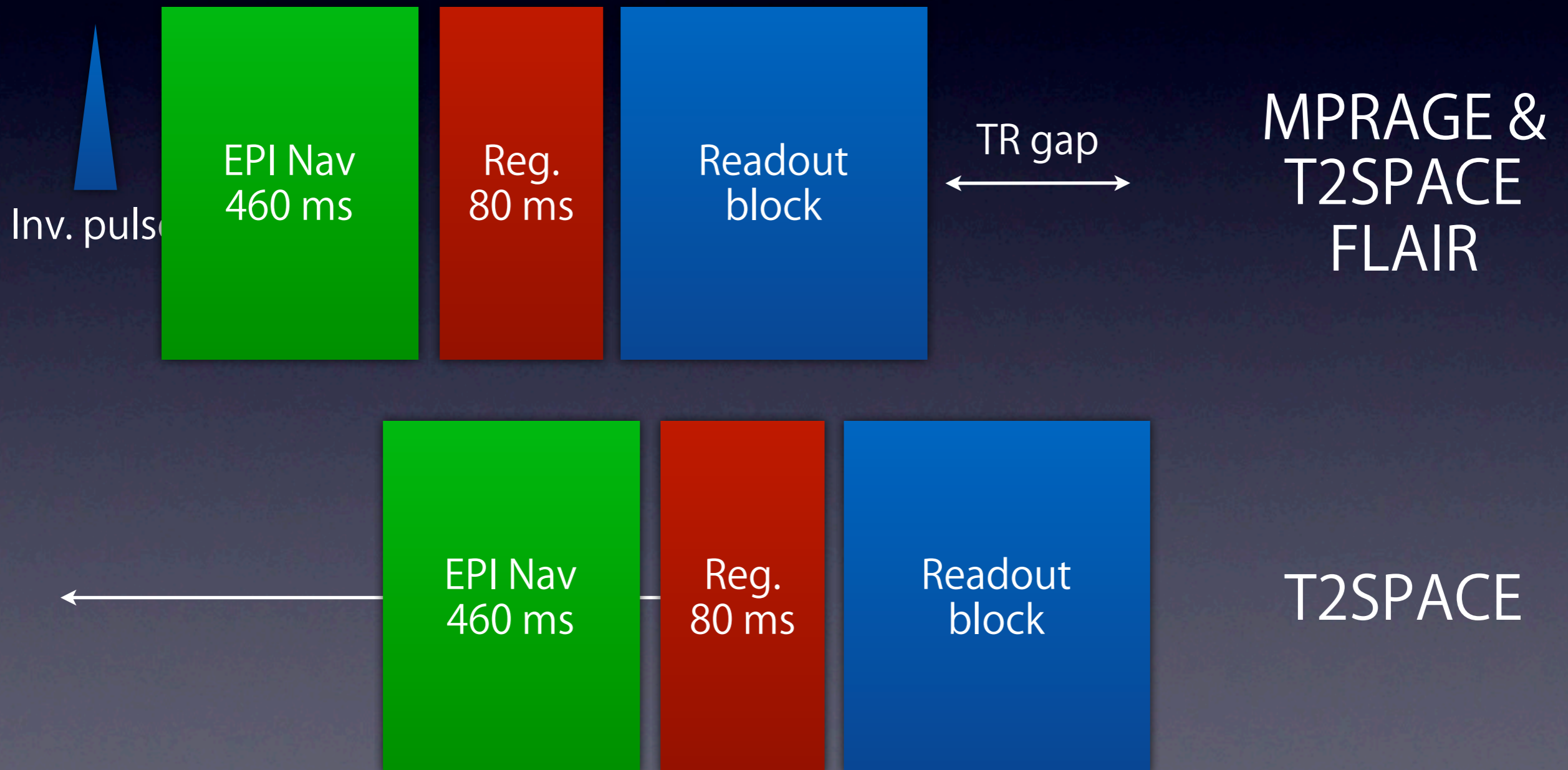


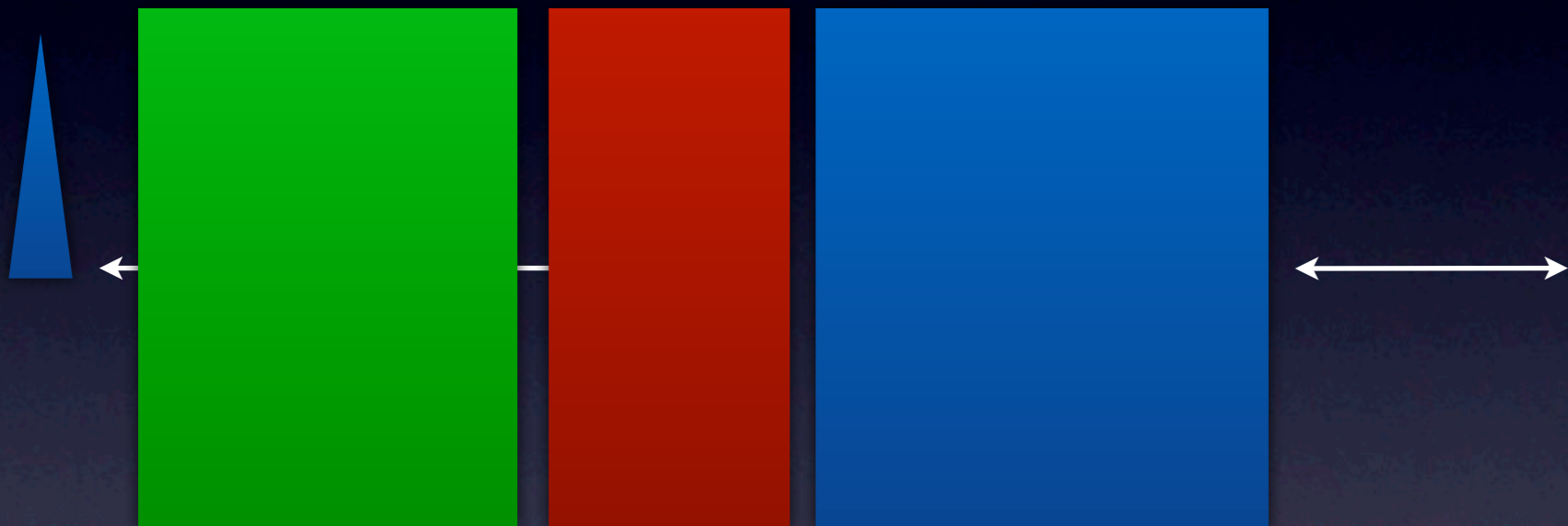
The Navigator

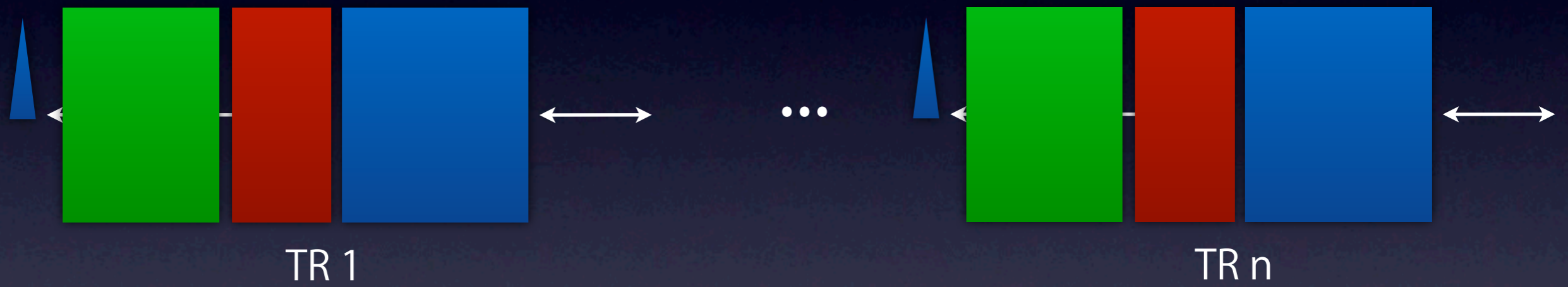
- 32^3 EPI
- 8 mm iso
- 256 mm FOV
- 32 shots
- TE 6.4 ms,
TR 13 ms
- **~ 460 ms**



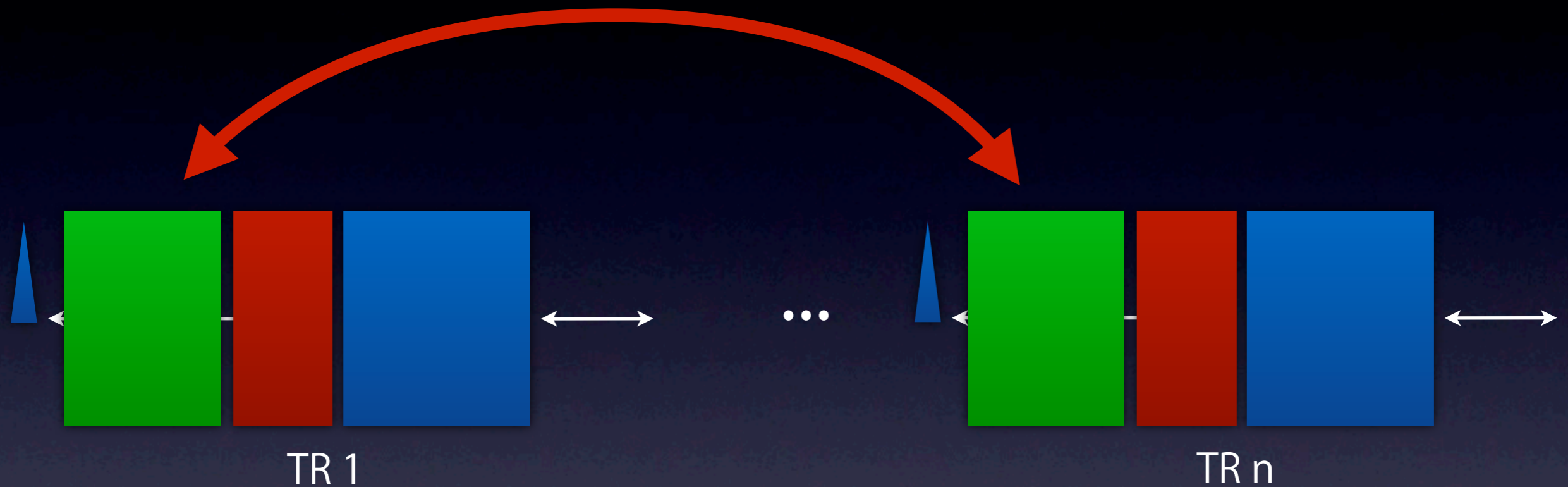
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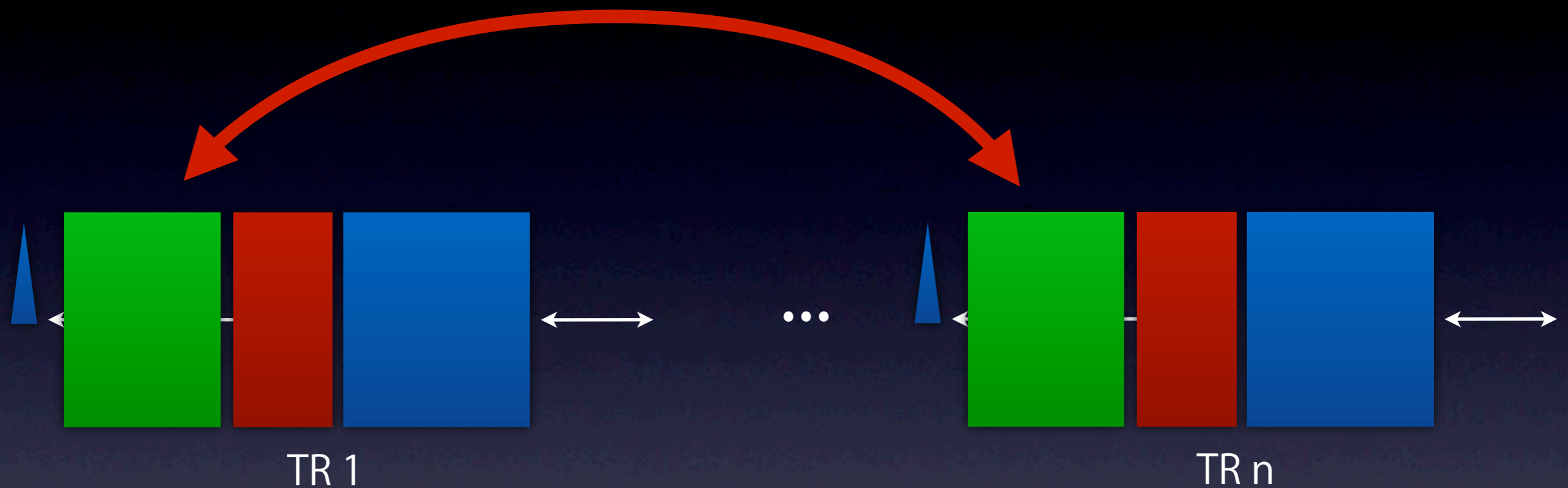




Register each EPI nav volume
back to first TR using Siemens'
PACE registration algorithm.



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PACE registration algorithm.



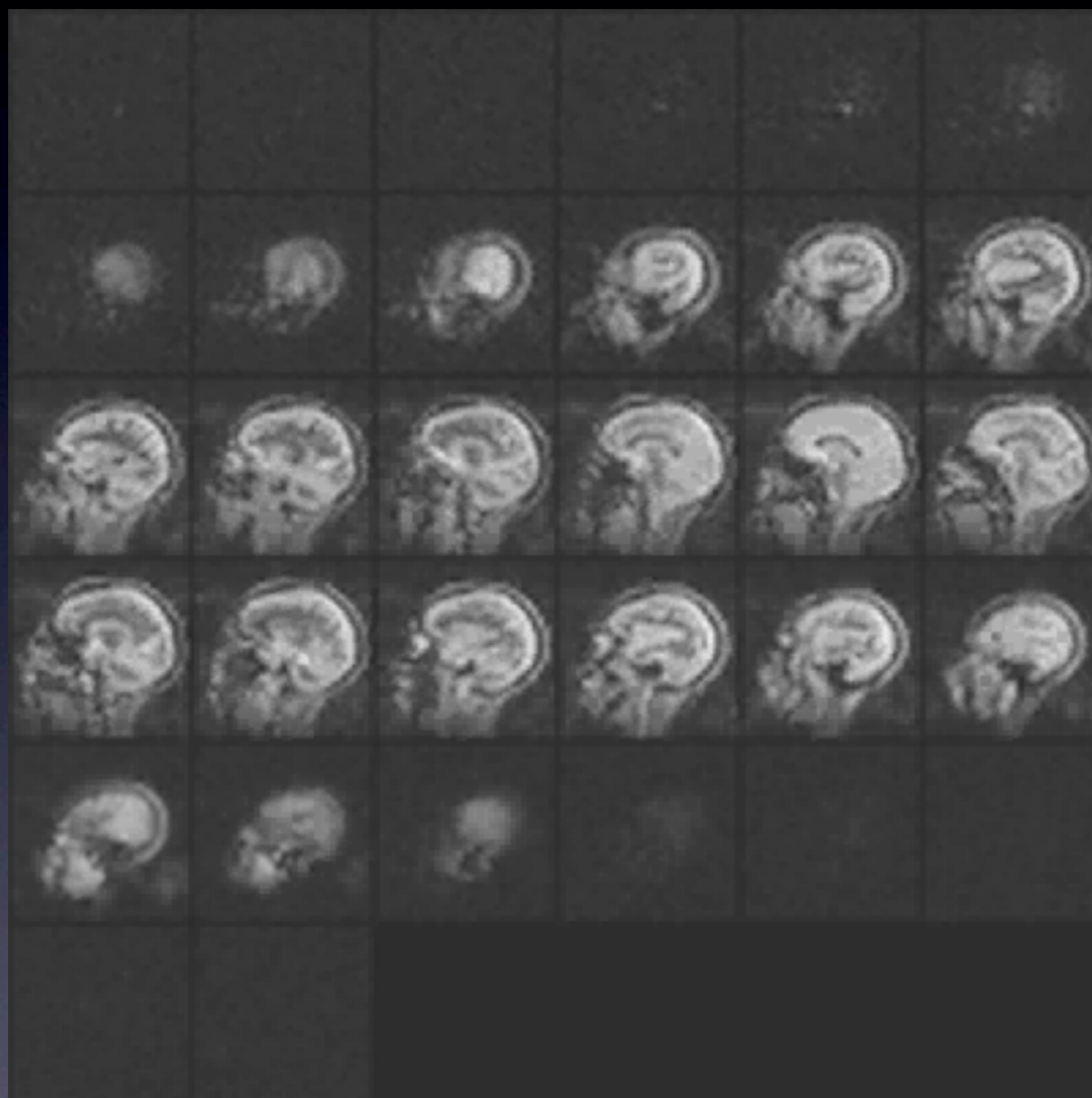
Observed variance of 50 microns at 3
T with stationary (pineapple) subject

EPI navigator volumes through time

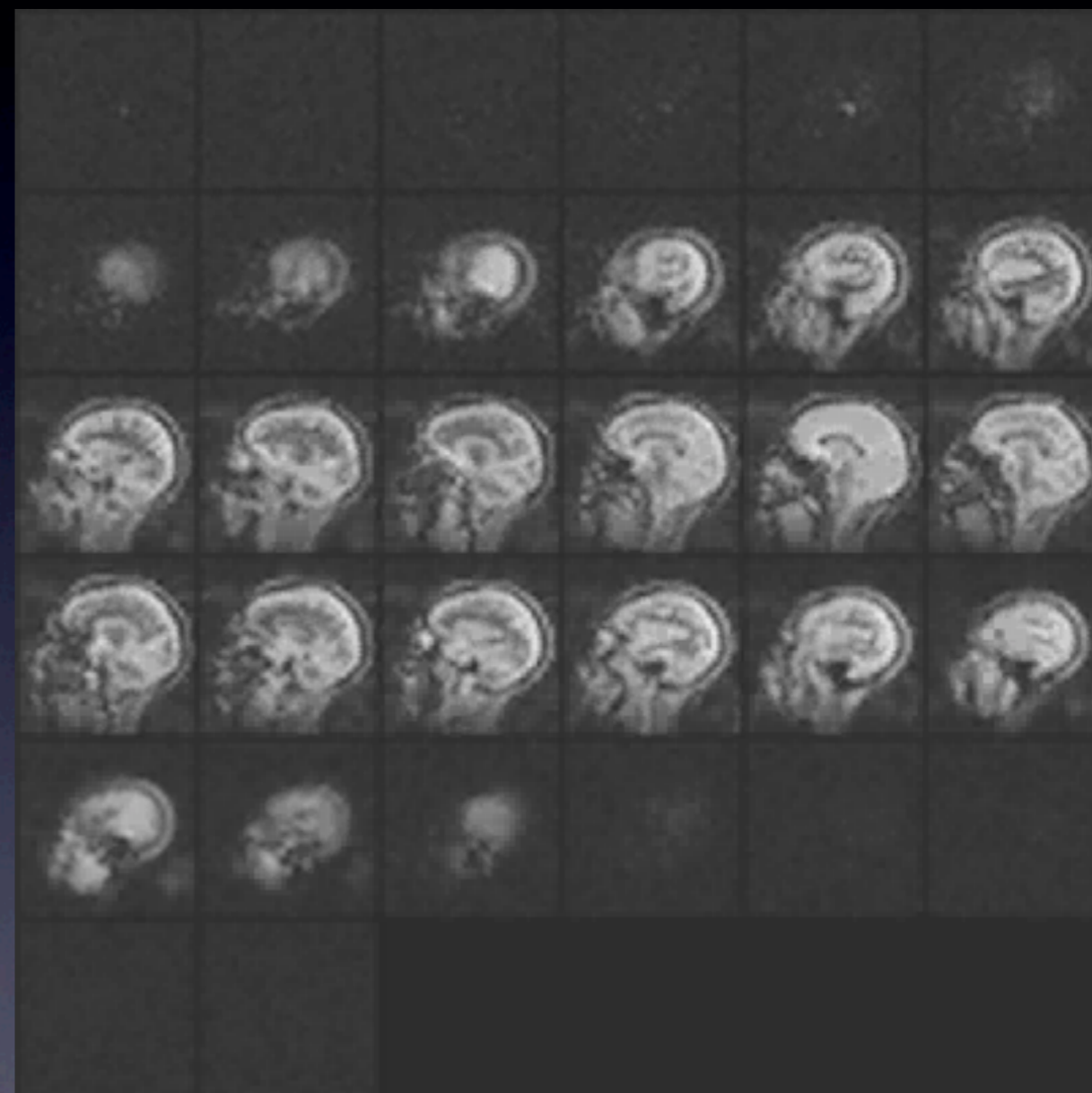
without prospective moco

with prospective moco

EPI navigator volumes through time

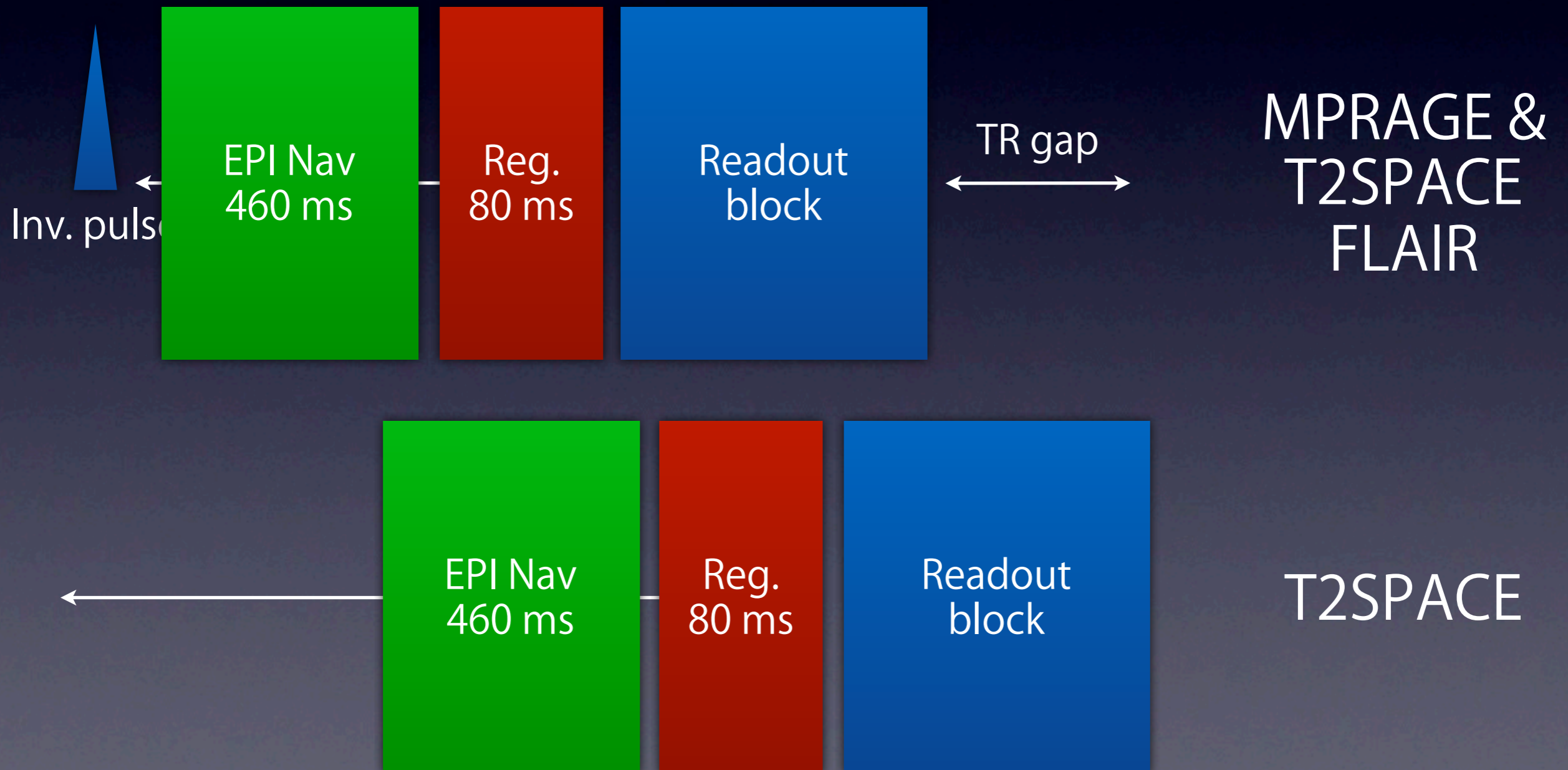


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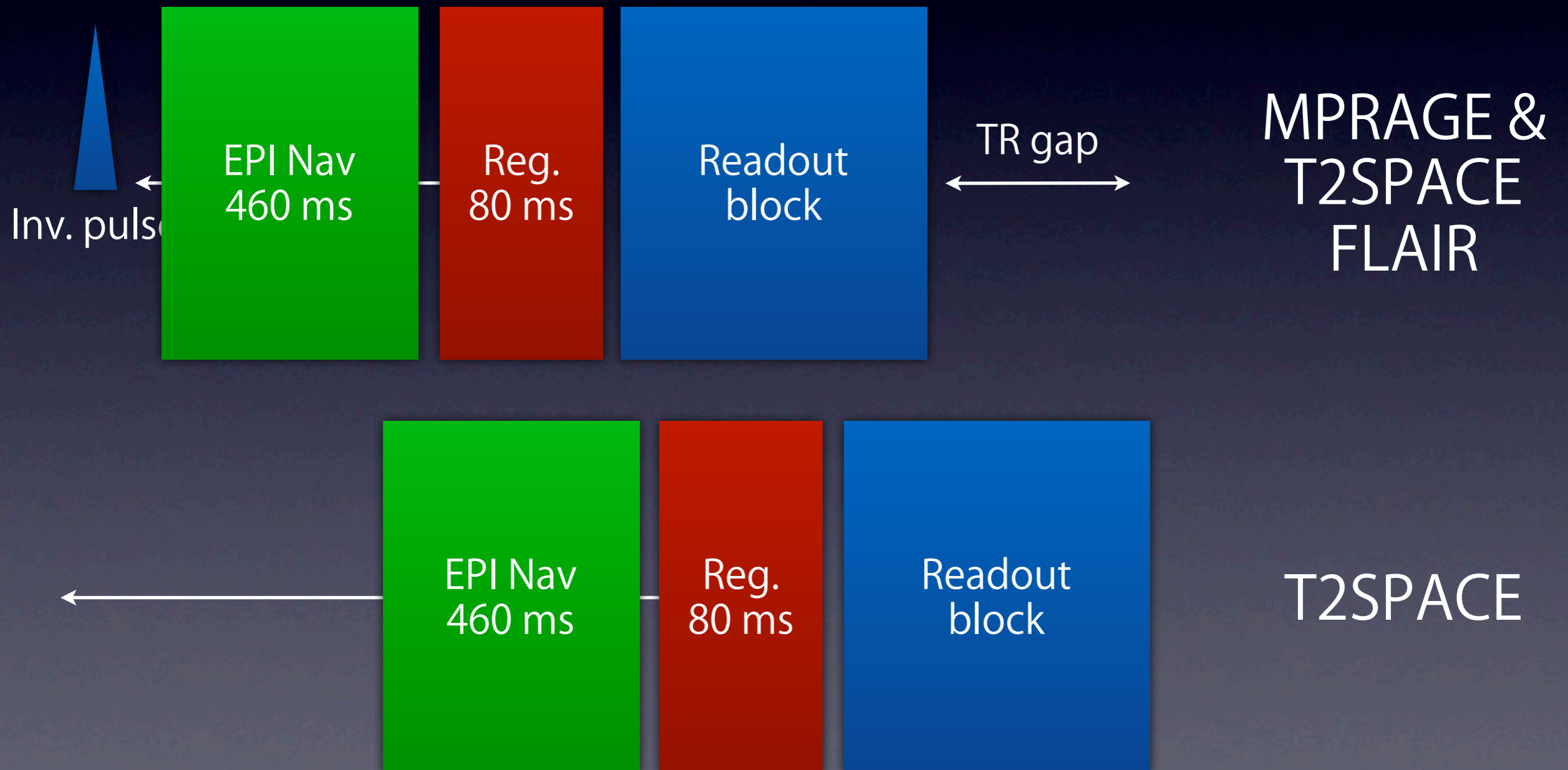
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Important considerations:



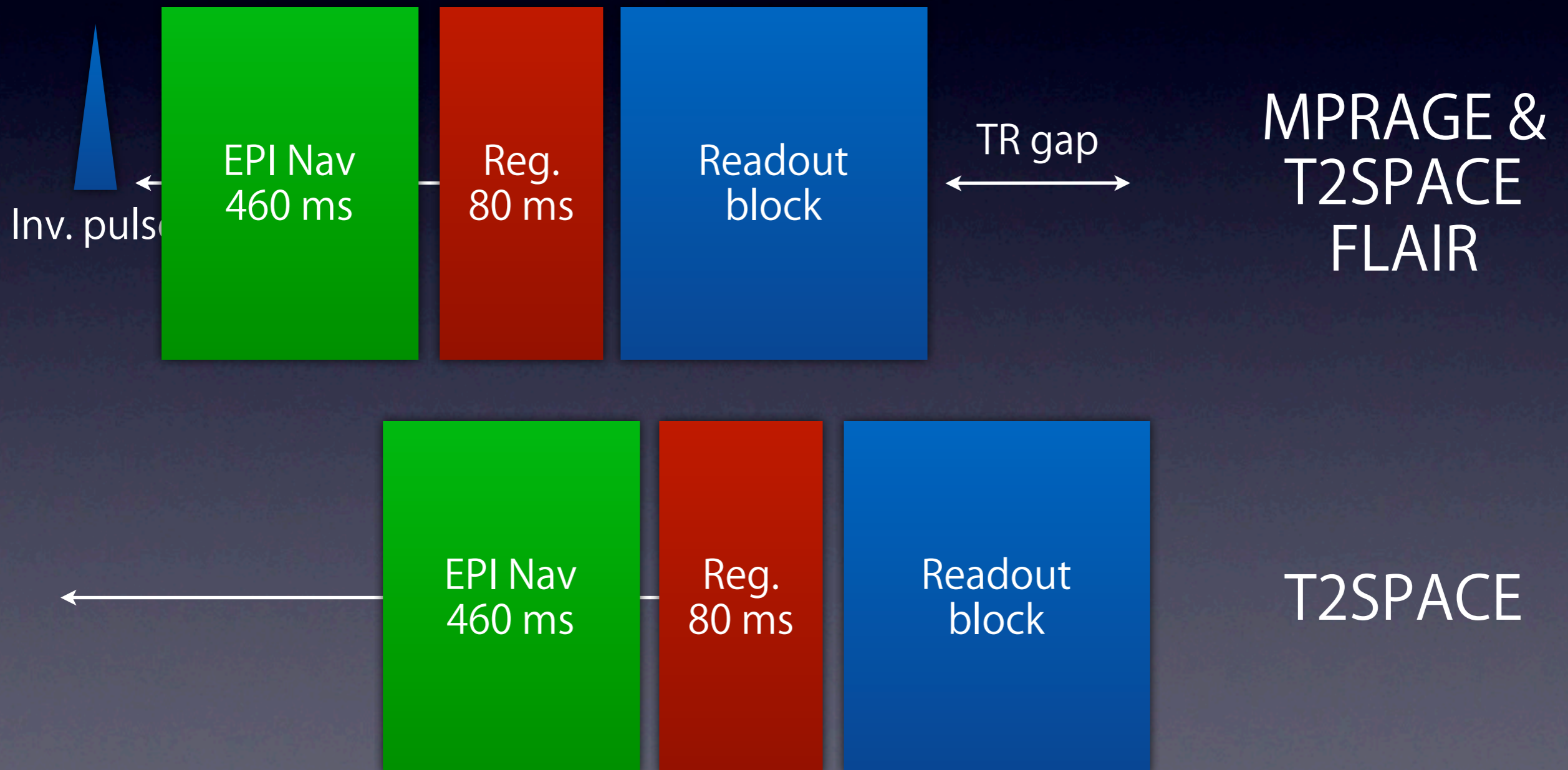
Nav before or after readout?

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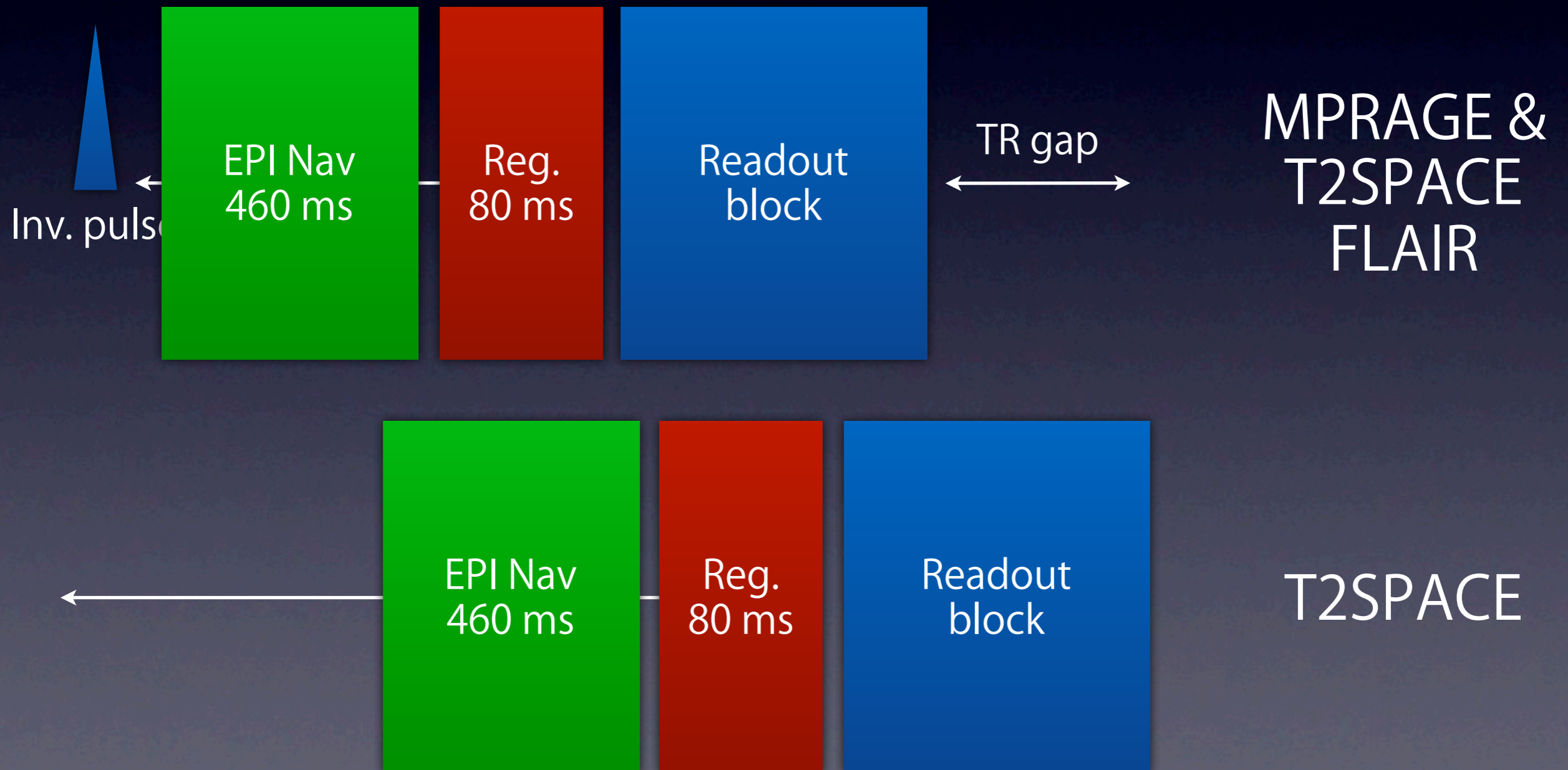
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Temporal filtering of nav?



Important
considerations:

Nav before or after readout?
Temporal filtering of nav?
Interaction between nav and parent?



Unsedated pediatric MPRAGE



without moco or navs



with navs and moco

images courtesy of Ellen Grant, Children's Hospital Boston

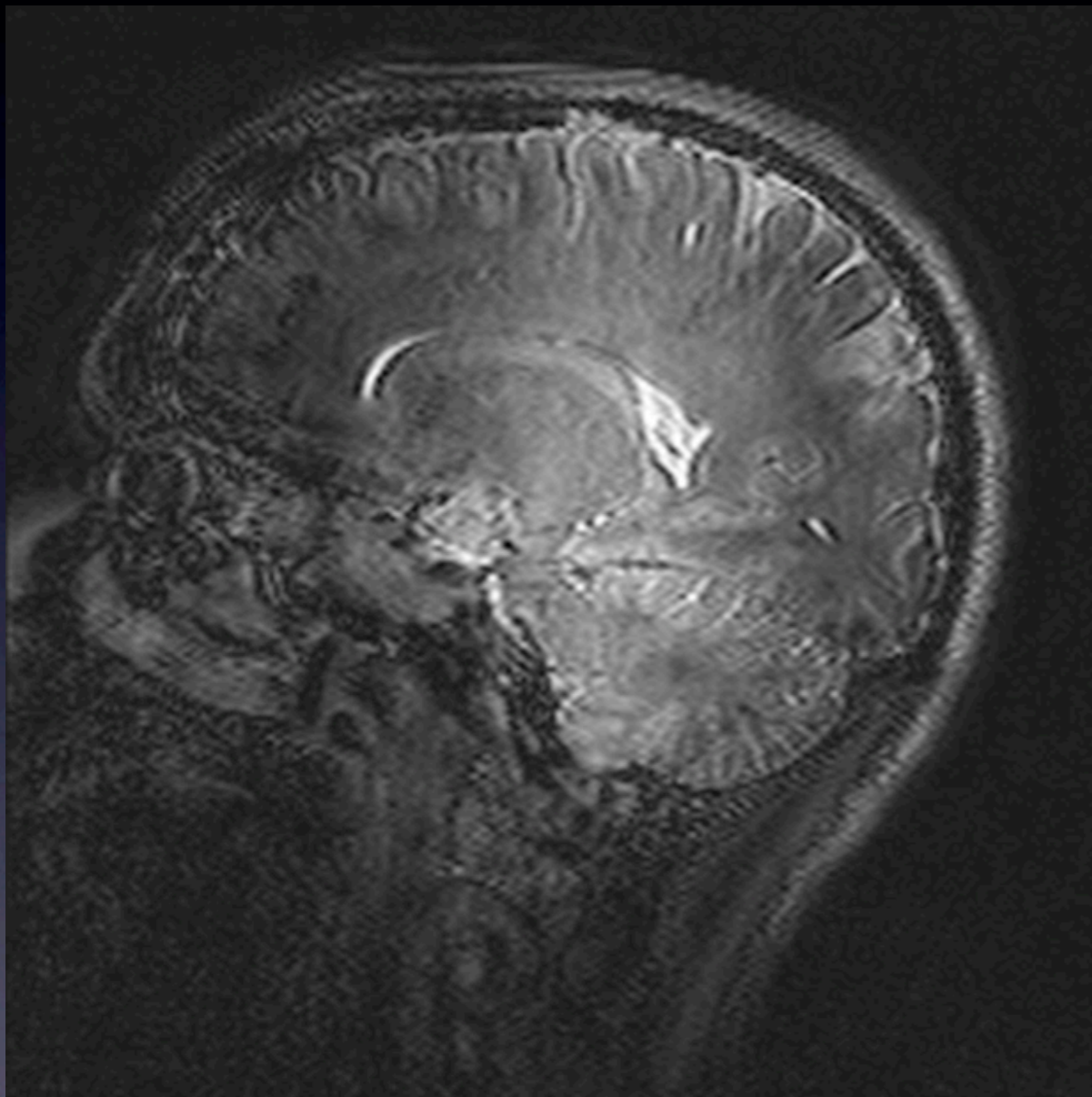
We have demonstrated:

- a modular framework that provides a <600 ms navigate-and-update block for prospective motion correction; and
- the application of this framework in three commonly used neuroanatomical sequences.

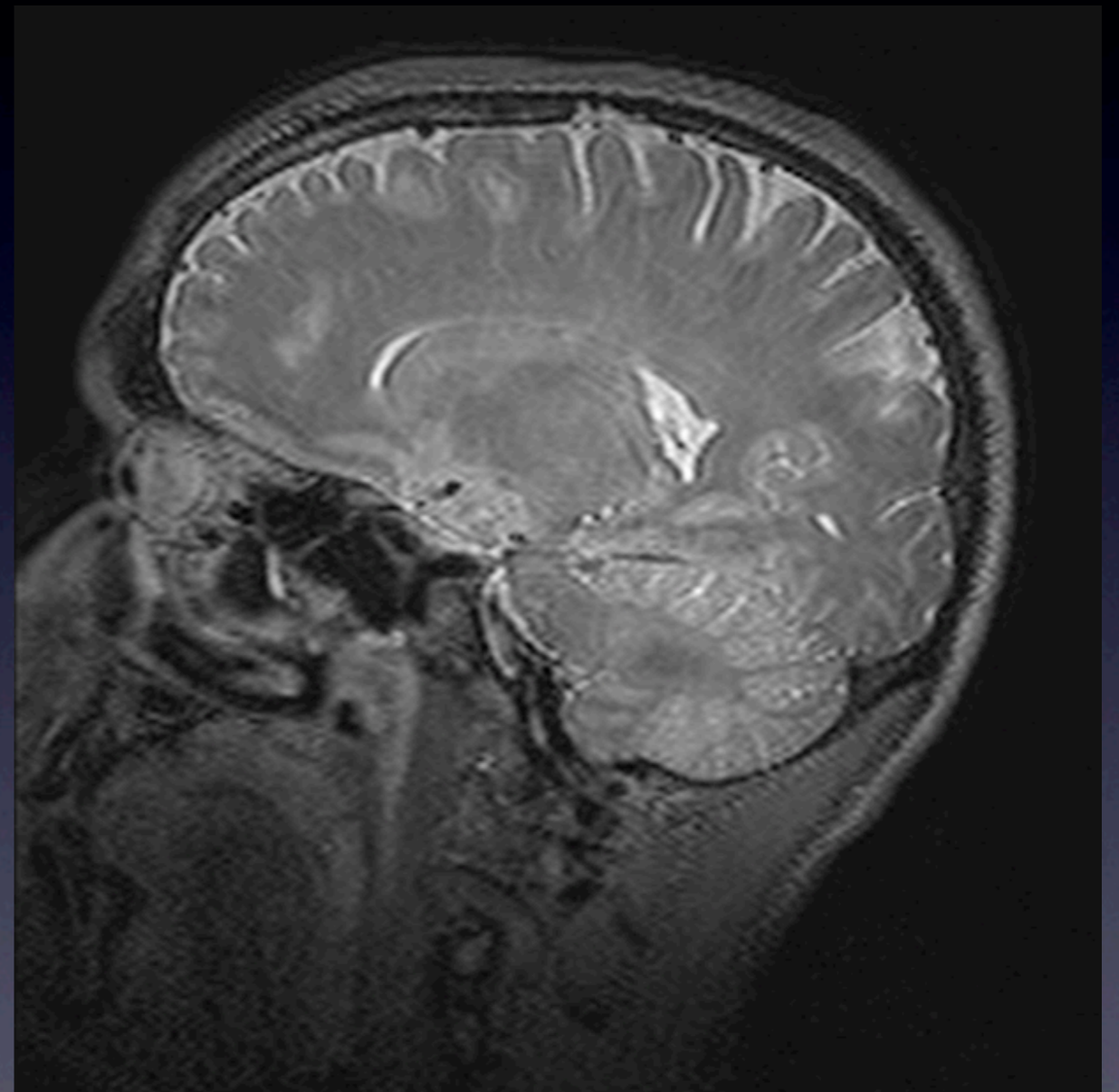
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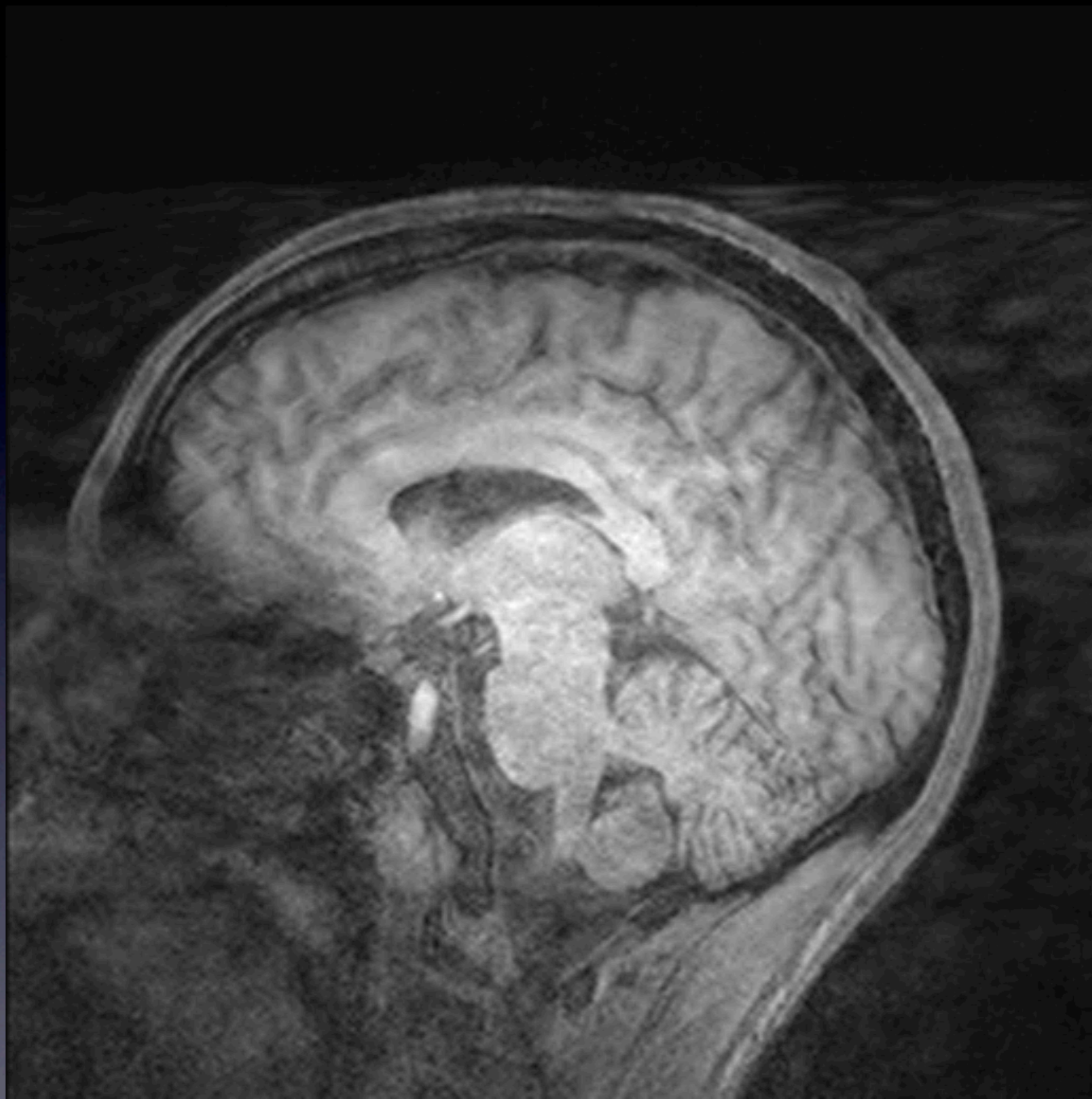
T2SPACE corrupted by 20 seconds of free motion during acquisition of center of k-space



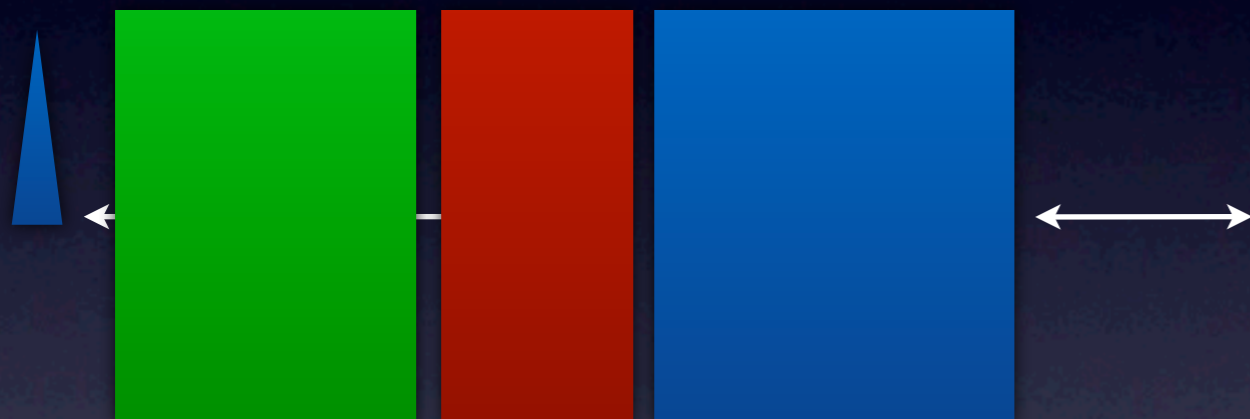
w/ moco
w/o reacquisition



w/ moco
w/ 10 TRs reacquired



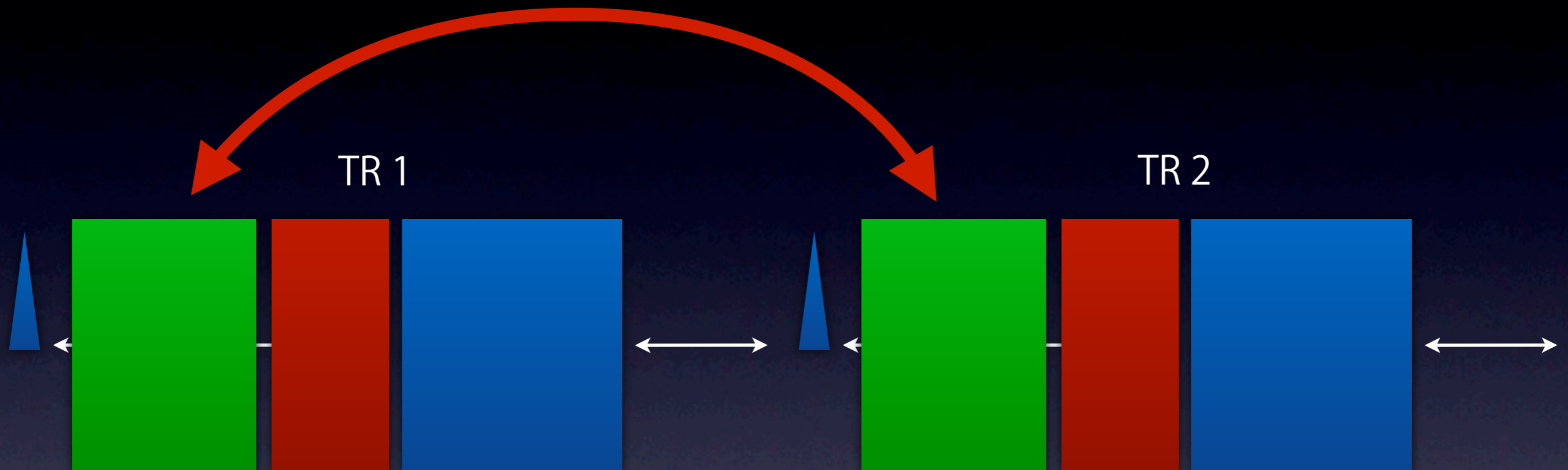
TR 1



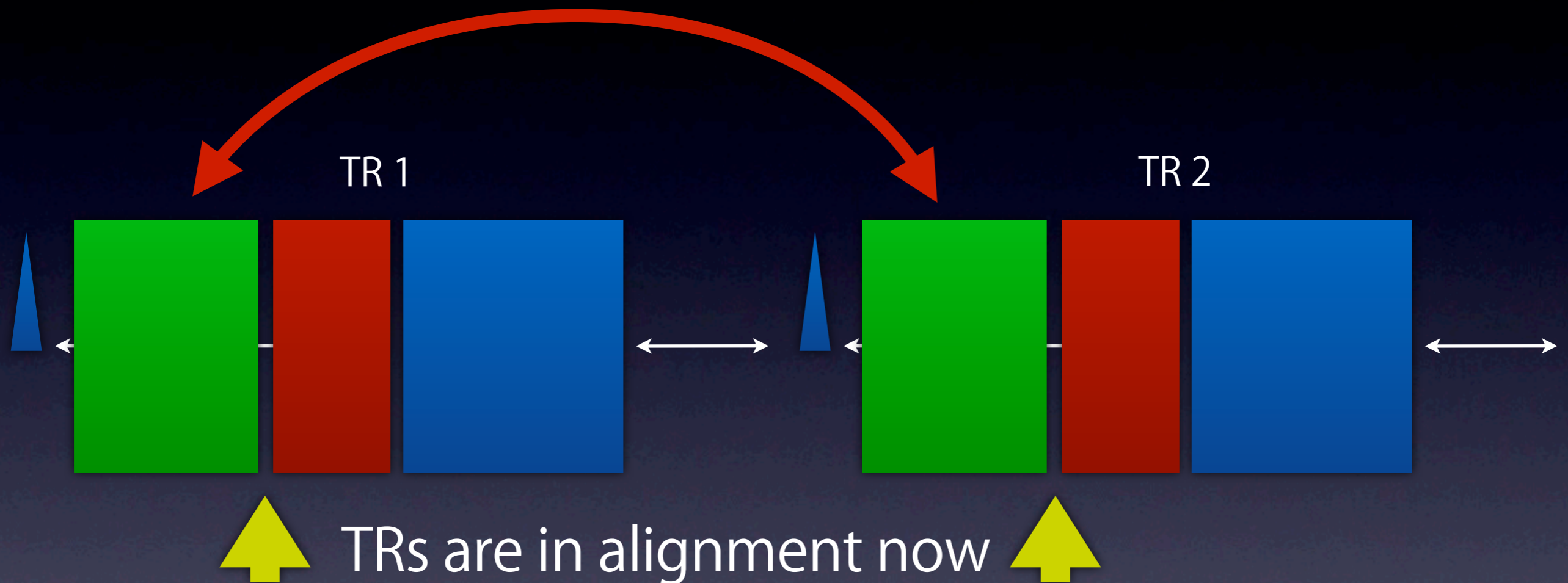
TR 2

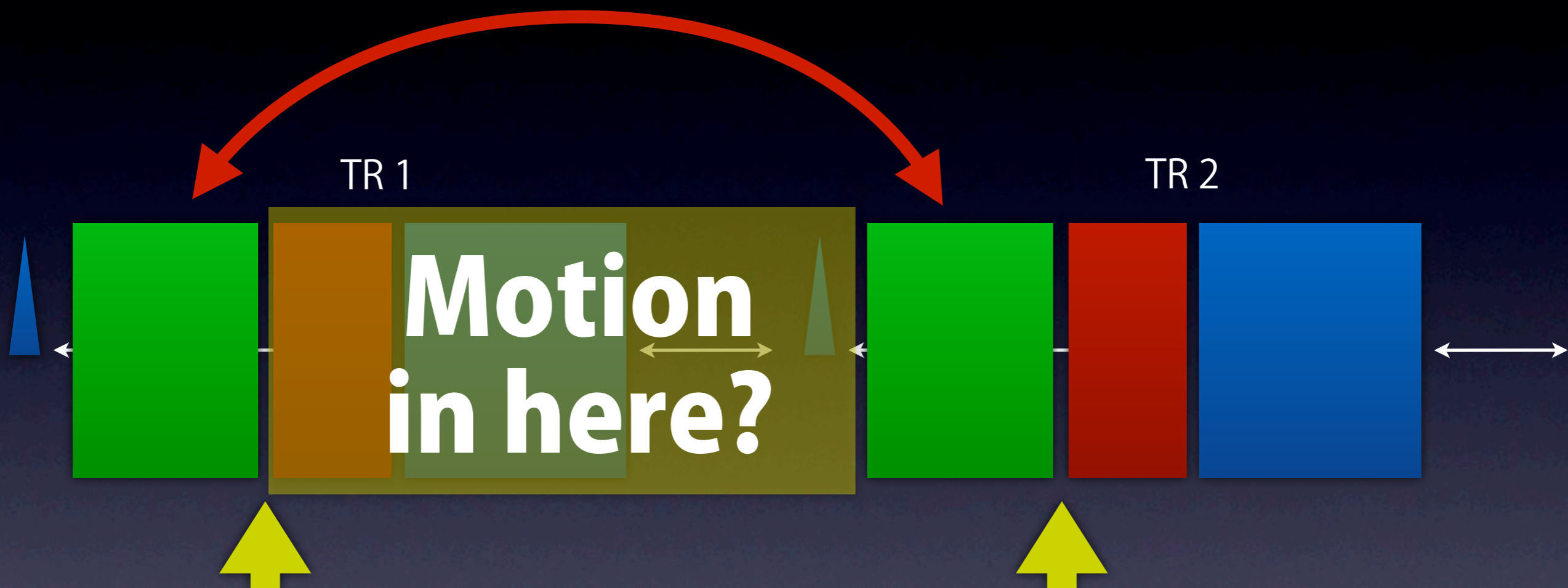


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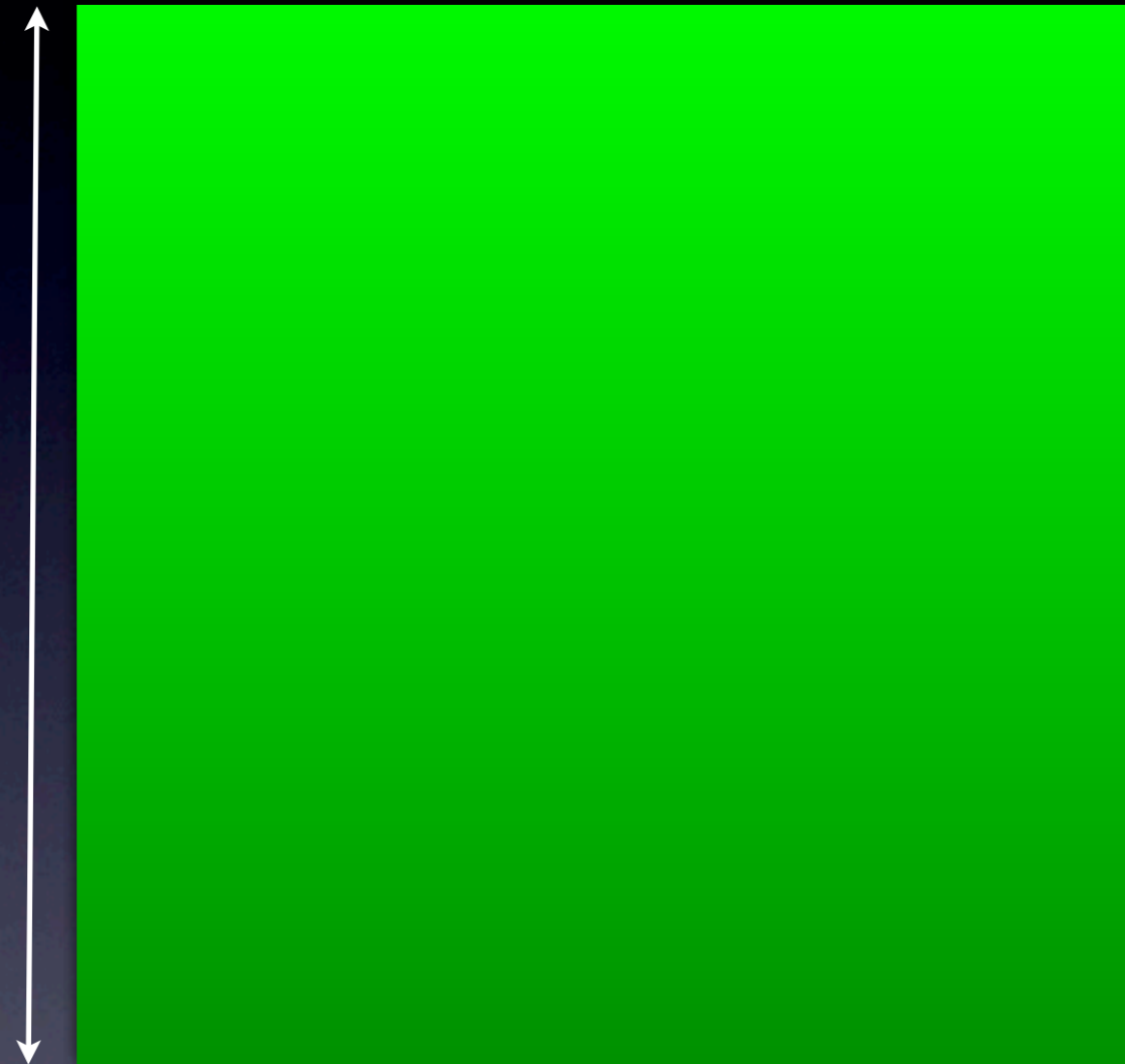




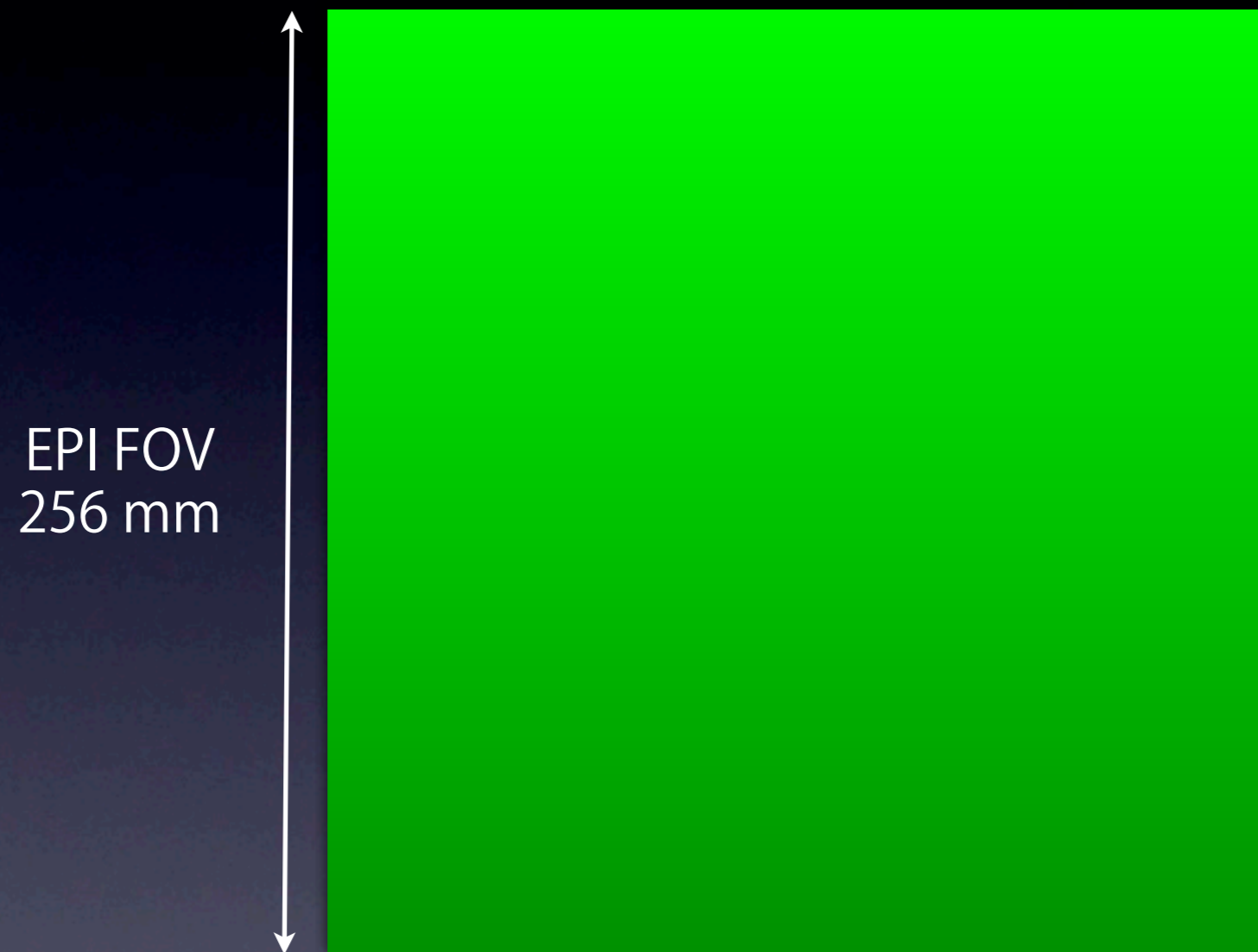
Convert translation and rotation
into single “motion score”

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into single “motion score”

EPI FOV
256 mm

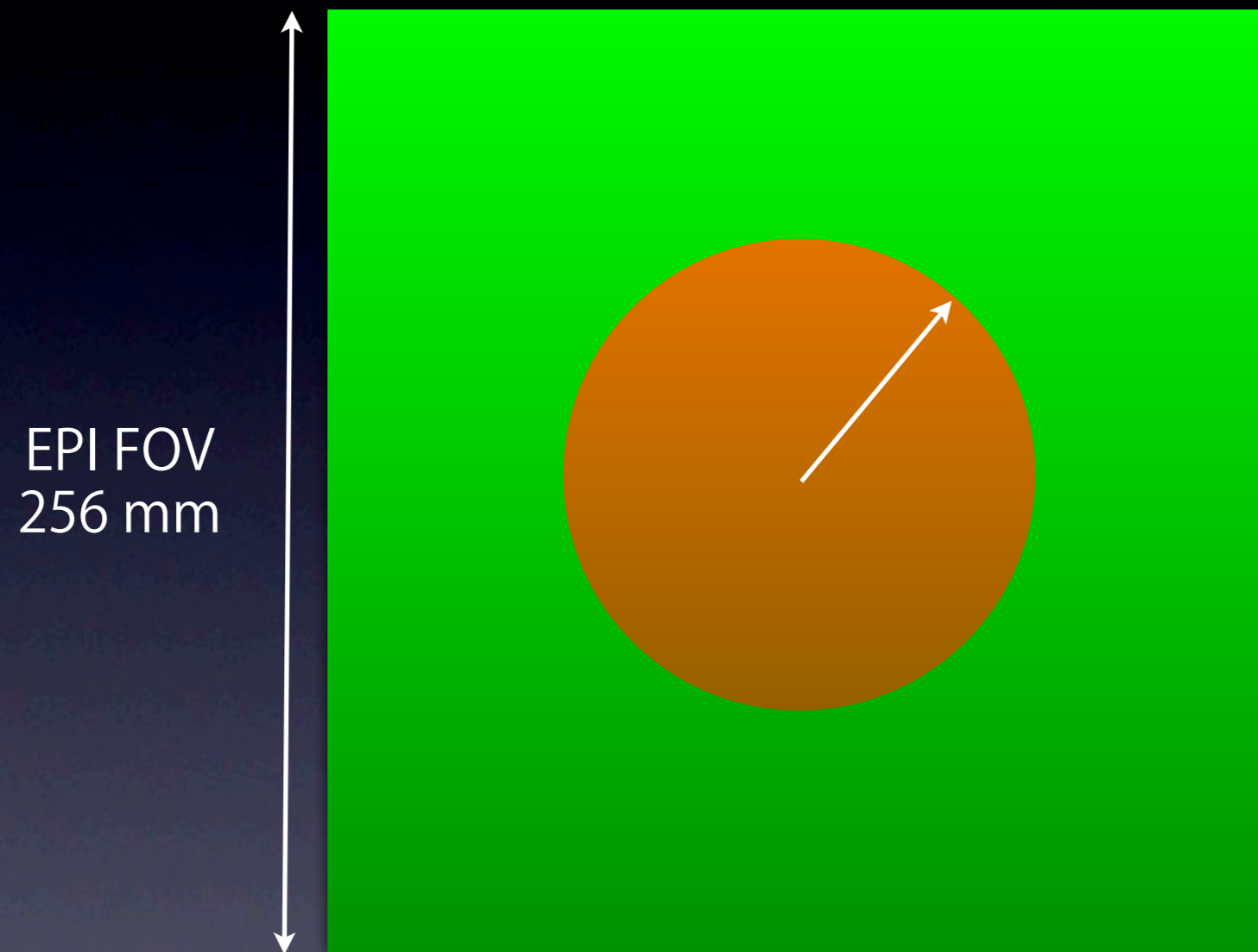


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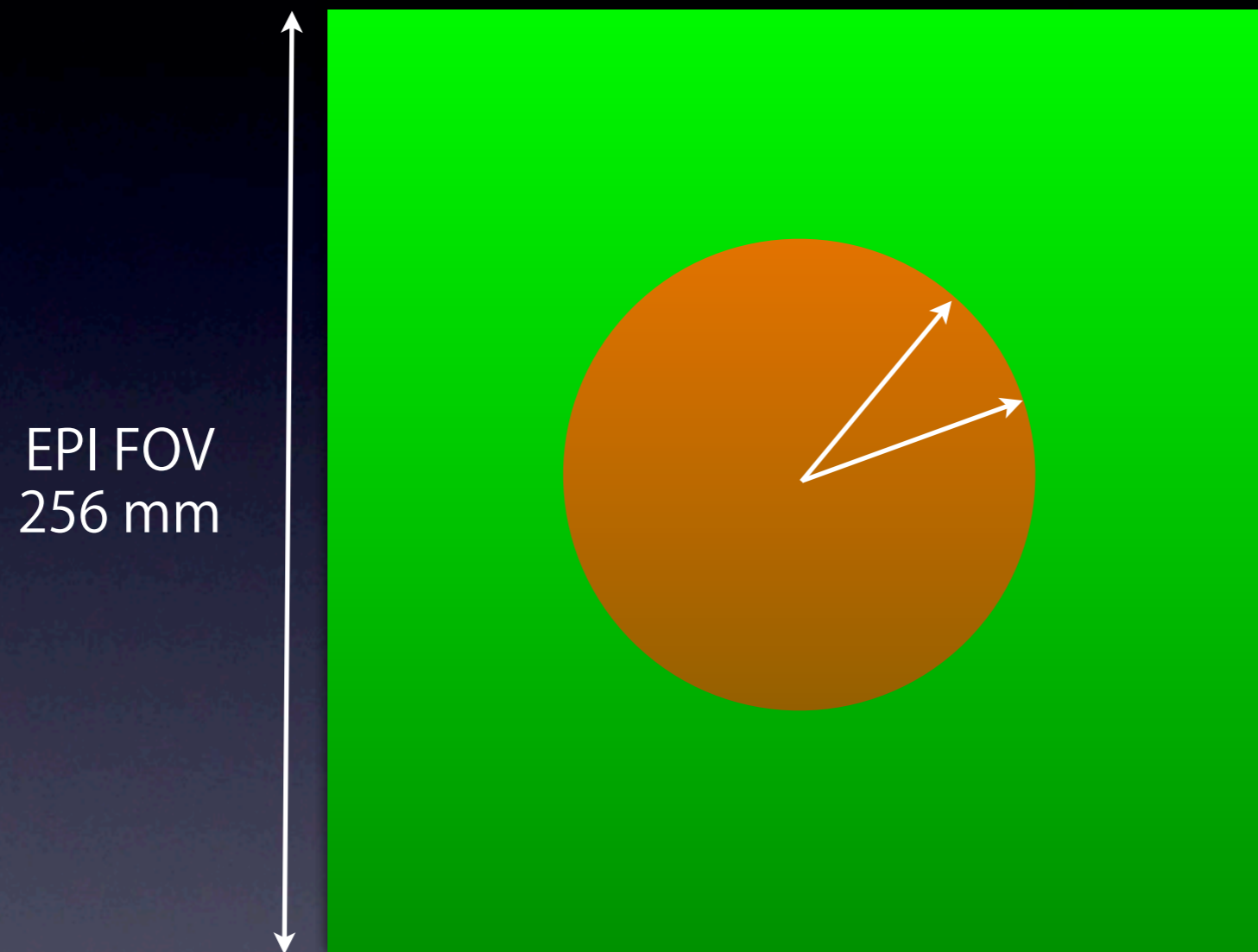
Convert rotation to worst-case translation

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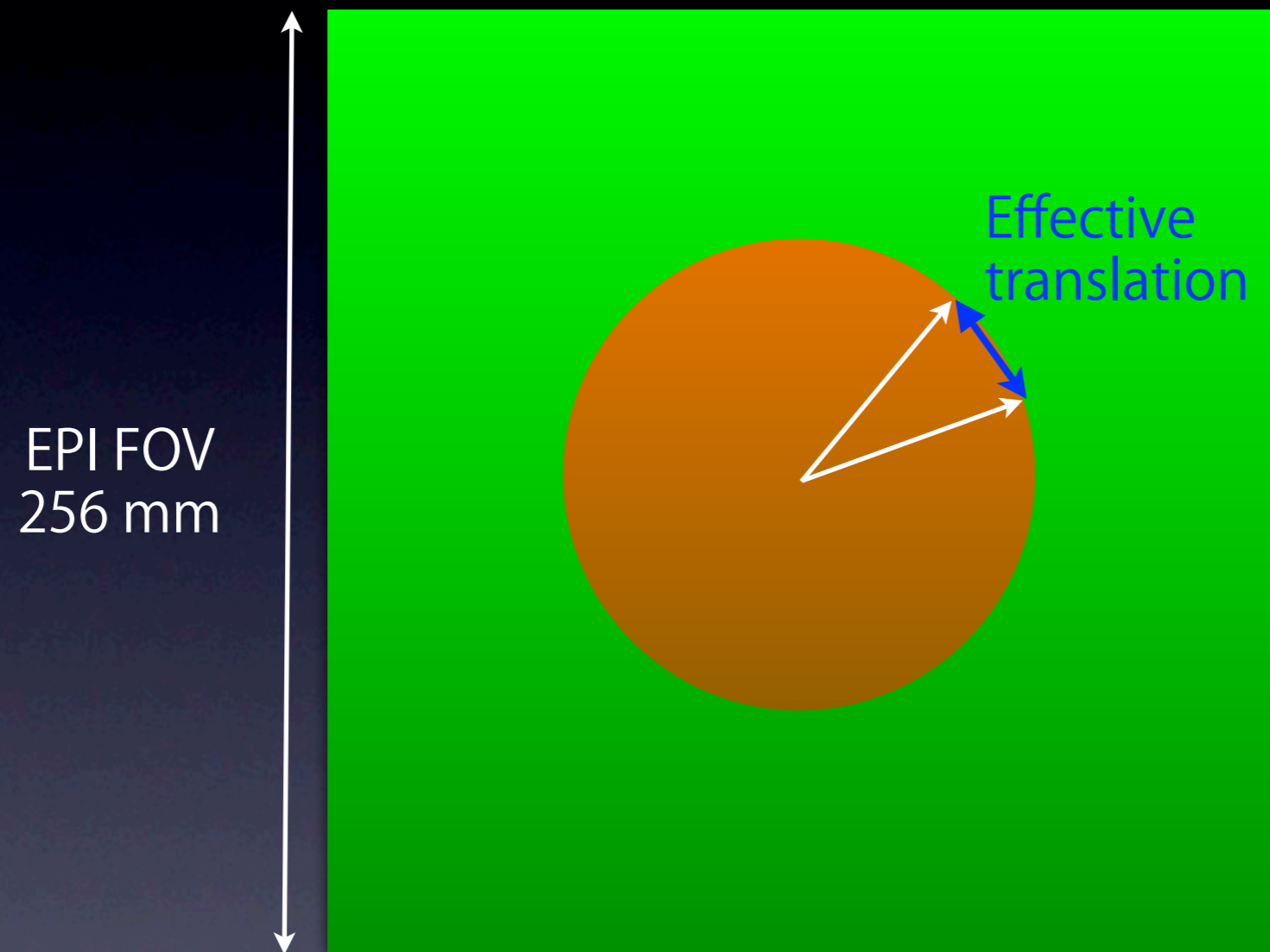
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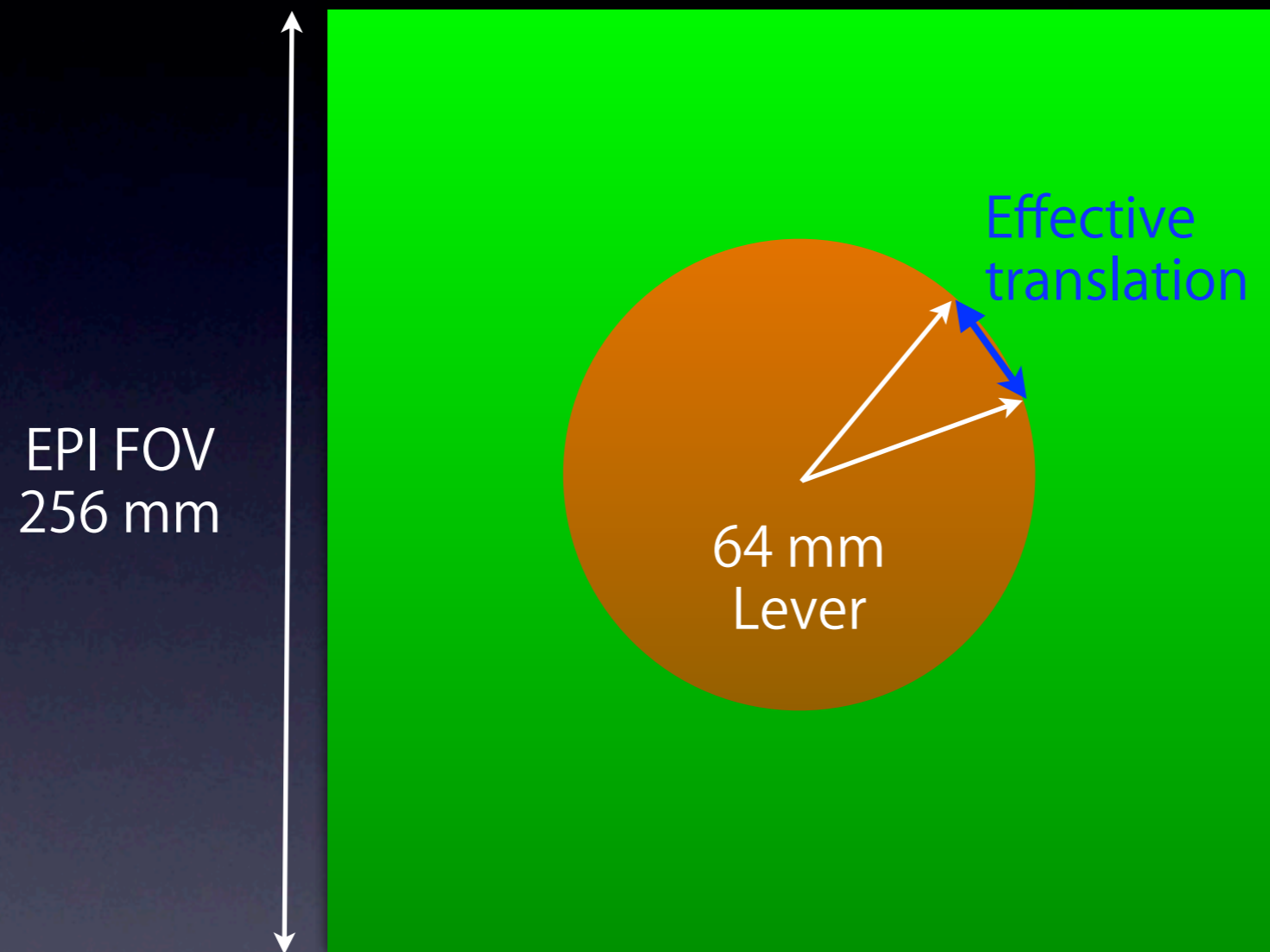
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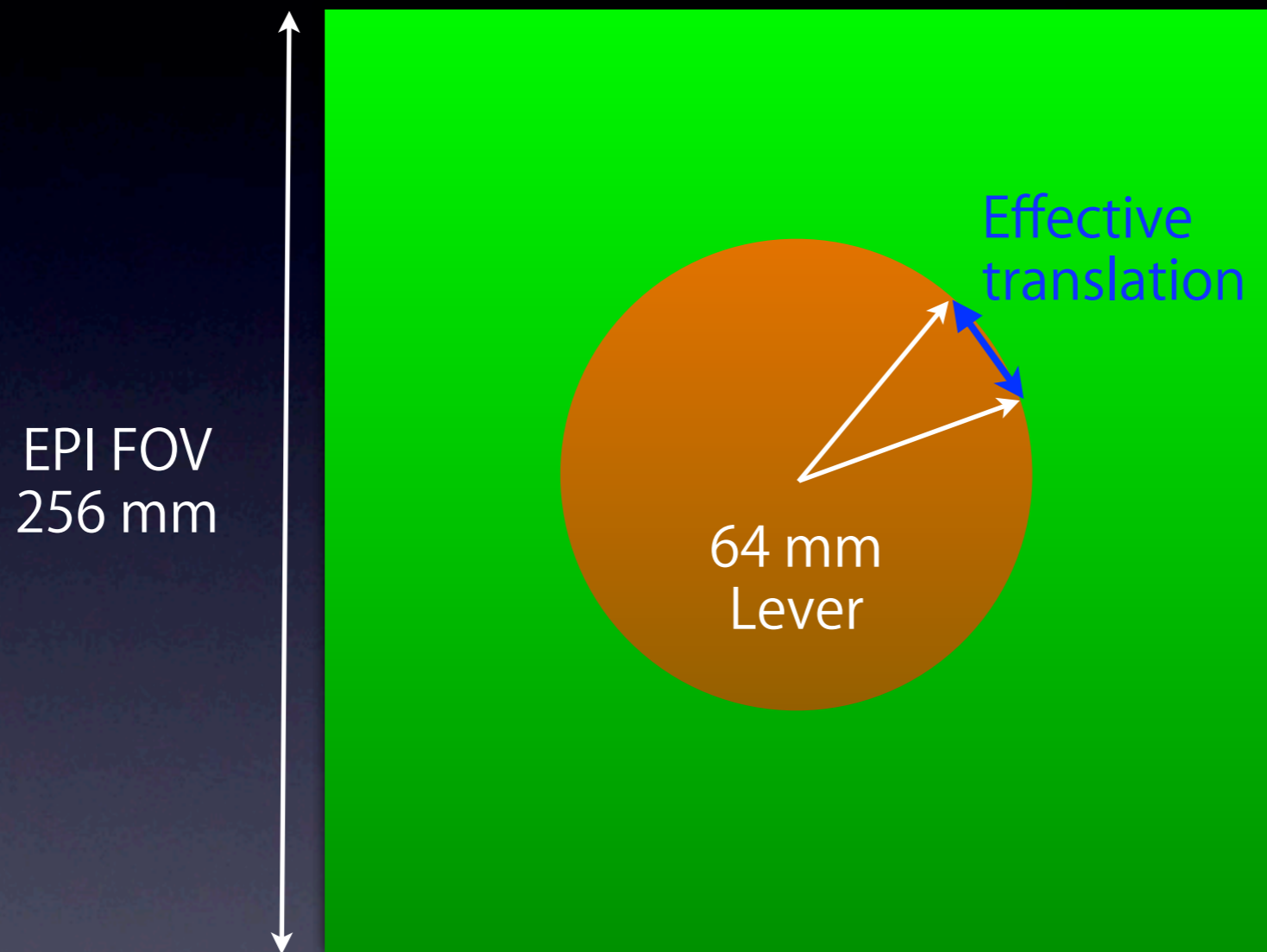
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Convert rotation to worst-case translation
then add translation to get final “score”.

Convert translation and rotation
into single “motion score”

$$\text{score} = 64\sqrt{(1 + \cos \theta)^2 + (\sin \theta)^2} + \text{translation}$$

Convert rotation to worst-case translation
then add translation to get final “score”.

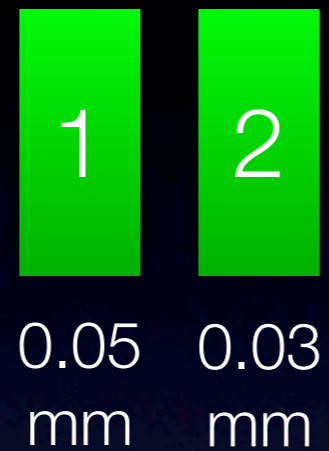
Form TRs into a motion-estimate priority queue.

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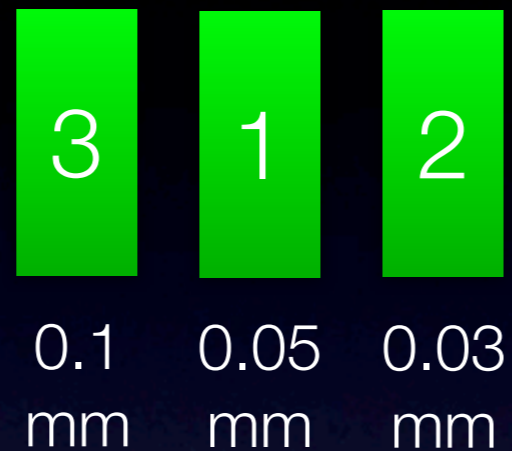


0.05
mm

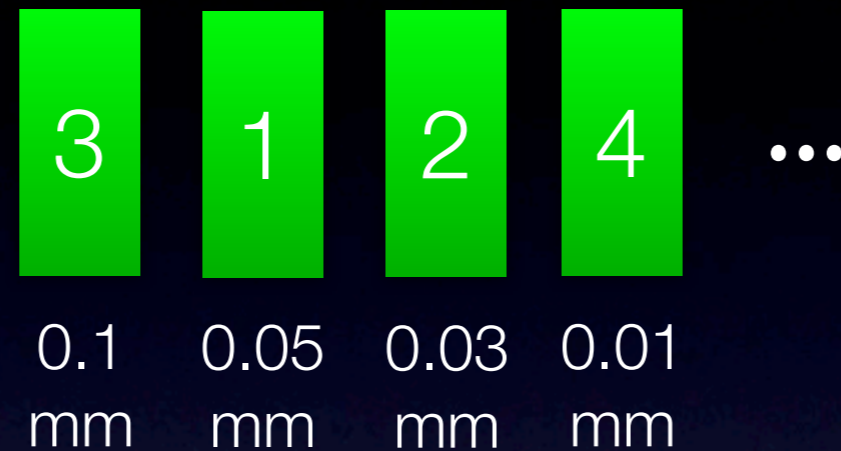
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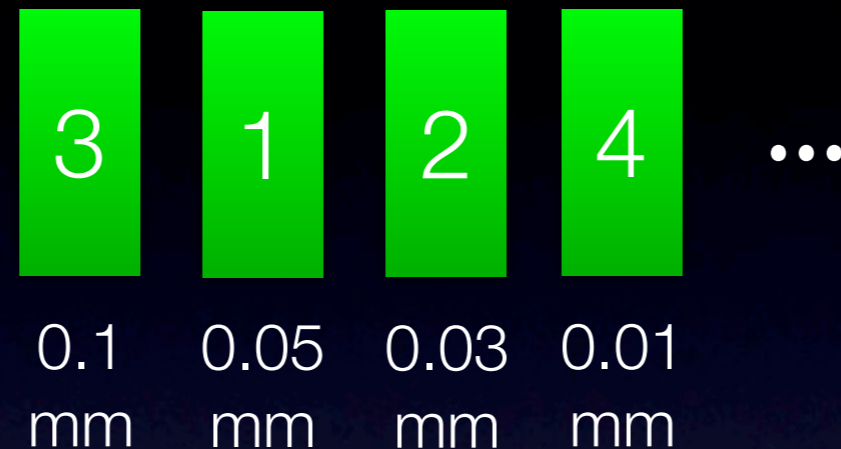
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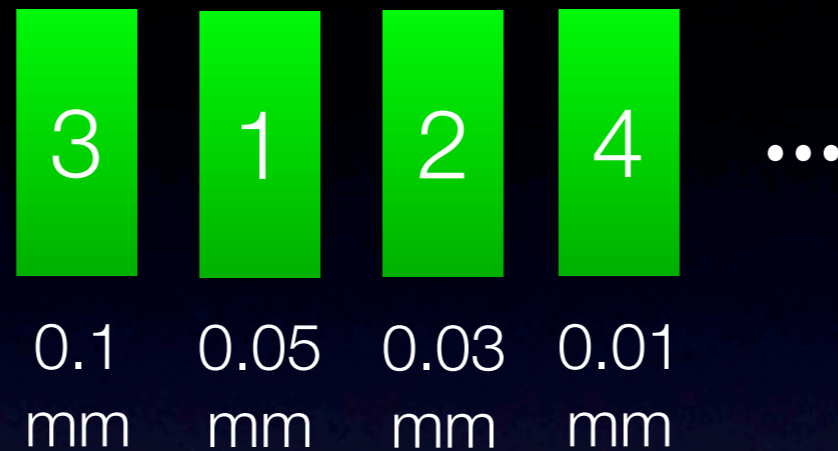


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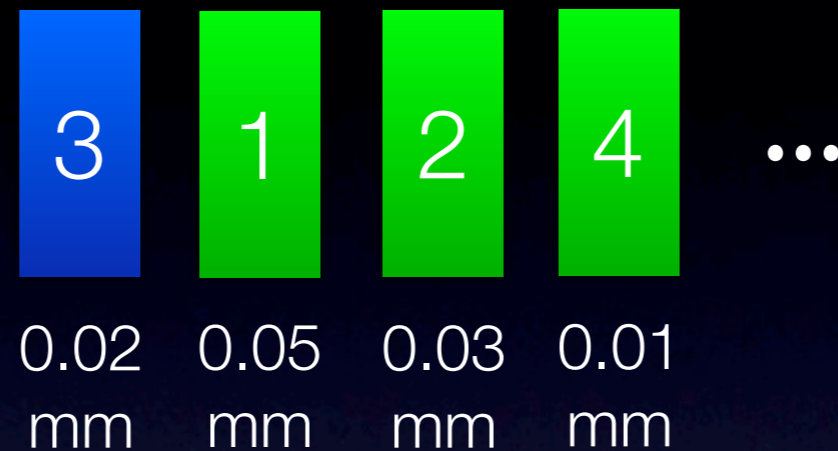
At end of scan, reacquire the worst TR and compute the new acquisition's motion score.



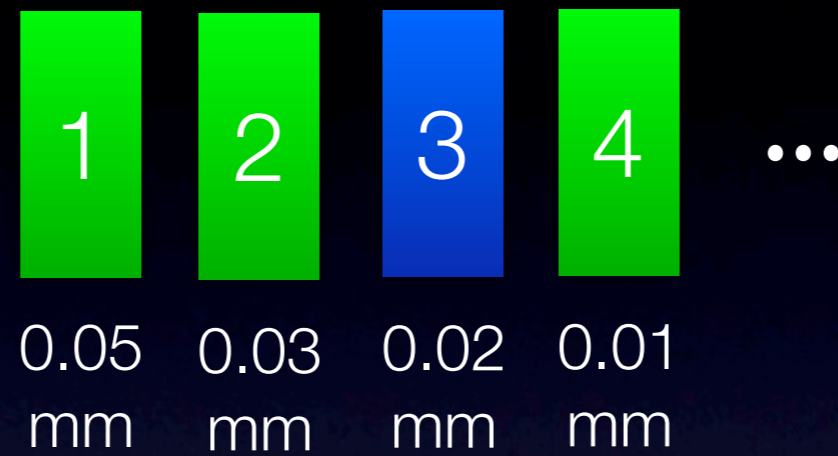


Compare motion estimates and keep the “better” version of that TR’s acquired data.

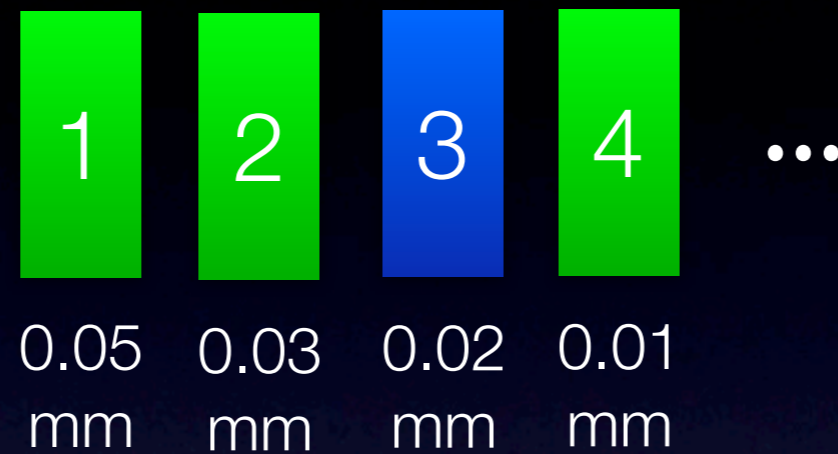




Compare motion estimates and keep the “better” version of that TR’s acquired data.



Update the ordering of the priority queue



Update the ordering of the priority queue
and reacquire the next TR at the top of the list.

Users configure the number of TRs to reacquire as part of their protocol.

The screenshot shows a software interface with a top navigation bar containing tabs: 'Part 1', 'Part 2', 'Special', and an unlabeled tab. The 'Special' tab is active. Below the tabs, there are three settings:

- 'Add. scale factor' with a value of 1.0 and up/down arrow controls.
- 'Remeasure' with a value of 0 and up/down arrow controls, followed by the text 'TRs'.
- 'Apply motion correction' with a checked checkbox.

A vertical blue line is positioned to the right of the 'Remeasure' controls. At the bottom of the interface, there is a green progress bar labeled 'Remeasure' on the left. The bar has '0' at both ends and '1000' at the right end. Below the progress bar is a row of tabs: 'Routine', 'Contrast', 'Resolution', 'Geometry', 'System', 'Physio', 'Inline', and 'Sequence'.

Users configure the number of TRs to reacquire as part of their protocol.

Part 1 Part 2 Special

Add. scale factor 1.0

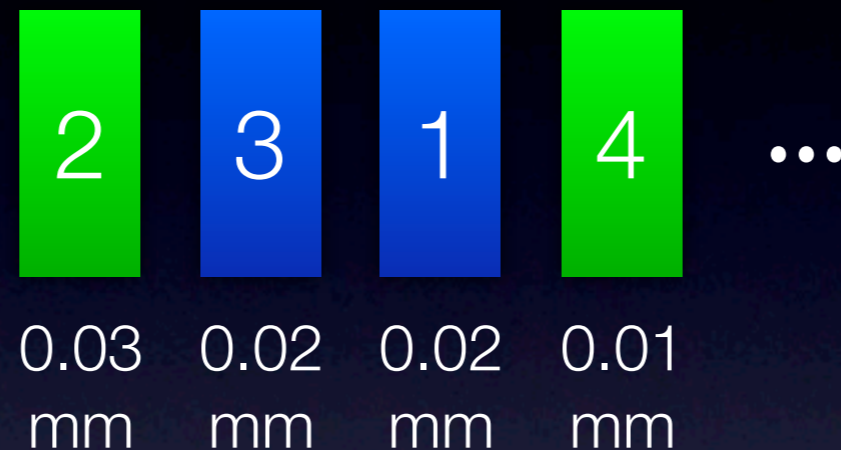
Remeasure 0 TRs

Apply motion correction ☒

Remeasure 0 1000

Routine Contrast Resolution Geometry System Physio Inline Sequence

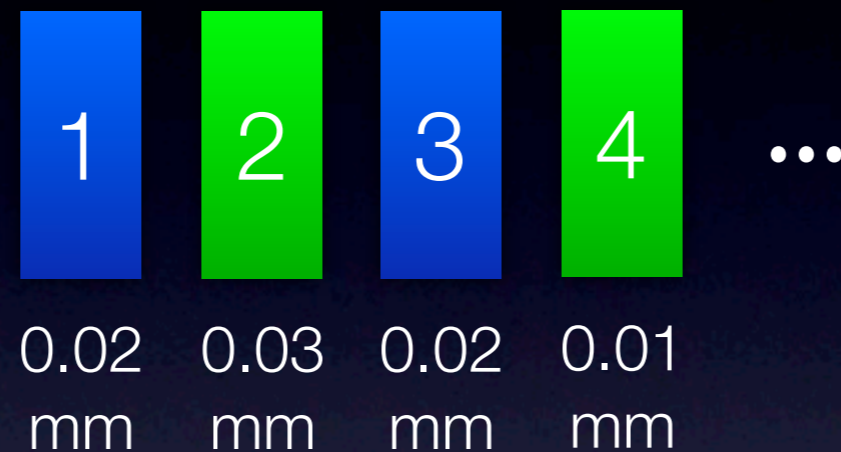
After reacquisitions are completed, reorder
“best” TR k-space data into “synthetic” acquisition order



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“best” TR k-space data into “synthetic” acquisition order



then release data into standard reconstruction pipeline.

What about inner vs. outer k-space regions?

Shouldn't that affect priority too?

What about inner vs. outer k-space regions?

Shouldn't that affect priority too?

Yes!

(I'm working on that)

We have demonstrated:

- a modular framework that allows automatic reacquisition of k-space regions damaged by subject motion without user intervention; and
- the application of this framework, with a granularity of one TR, in three commonly used neuroanatomical sequences.

Key differences from PROMO:

- Navigator is acquired once per TR
- Navigator is a full 3D volume, not slices
- Navigator excitation is non-selective
- Navigate-and-update occurs immediately before readout

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Key differences from “non-moco” sequences:

- You **must** run a navigator “setter” sequence at the start of your session (takes 500 ms).
- Sequences produce two image series: the navigators, and the anatomical volume.
- Contrast in the sequences is subtly different (longer TI, shorter TE; still works in FreeSurfer).
- Navigator excitations **don’t** affect contrast
- Motion logs are saved for every scan
- With reacquisition enabled, scans are longer (you decide how much).

Motion-correction in practice:

- Like PACE, limited to 20 mm of motion and 8 degrees of rotation per TR.
- If subject moves more, no motion-tracking for remainder of sequence (PACE error pops up).
- **You get your images, even if PACE fails.**

Regular Scan
Time

Reacq
Time



Regular Scan
Time

Reacq
Time

Subject moves
too much



Regular Scan
Time

Reacq
Time

Subject moves
too much



Regular Scan
Time

Reacq
Time

Motion-
corrected

Subject moves
too much



Regular Scan
Time

Reacq
Time

Motion-
corrected

Make images



Regular Scan
Time

Reacq
Time

Motion-
corrected

Regular Scan
Time

Reacq
Time



Regular Scan
Time

Reacq
Time

Subject moves
too much



Regular Scan
Time

Reacq
Time

Subject moves
too much



Regular Scan
Time

Reacq
Time

Motion-
corrected

Stop right away and
make images



Regular Scan
Time

Reacq
Time

Motion-
corrected

Other sequences:

- Single-voxel spectroscopy and CSI are both in experimental state (Aaron, Ovidiu, Oliver, and André).
- Diffusion systems in experimental state (Ali and André; Thomas)

Acknowledgements:

- Aaron Hess
- André van der Kouwe
- Oliver Hinds
- Thomas Benner
- Michael Hamm
- NIH grants R21EB008547, R21AA017410, R21DA026104, R01NS055754, P41RR014075
- The Ellison Medical Foundation