Imaging is a Numbers Game: Challenges and Breakthroughs in CT Quantitative Imaging

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Today's Goal

- Illustrate the **major obstacles facing the clinical adoption of quantitative imaging** (with specific focus on CT imaging)
- Highlight **technological solutions we are developing** to overcome these challenges

Quantitative CT Imaging

- 1971: First CT scan
- 1
- 1
- 1
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- correctly

Compa... topic Morph...

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DANIÈLE JA...

Departments o... Brussels, Belgium;
Statistical Unit, ... e Mons-Hainaut,
Mons, Belgium

Decoding tumour phenotype by noninvasive imaging using a quantitative radiomics approach

Hugo J. W. L. Aerts, Emmanuel Rios Velazquez, Ralph T. H. Leijenaar, Chintan Parmar, Patrick Grossmann, Sara Carvalho, Johan Bussink, René Monshouwer, Benjamin Haibe-Kains, Derek Rietveld, Frank Hoebers, Michelle M. Rietbergen, C. René Leemans, Andre Dekker, John Quackenbush, Robert J. Gillies & Philippe Lambin

...age feature analysis and computer-aided diagnosis in digital radiography. I. Automated detection of microcalcifications in mammography

Heang-Ping Chan,[a] Kunio Doi, Simranjit Galhotra, Carl J. Vyborny, Heber MacMahon, and Peter M. Jokich
Kurt Rossmann Laboratories for Radiologic Image Research, Department of Radiology, The University of Chicago, Chicago, Illinois 60637

(Received 5 September 1986; accepted for publication 13 April 1987)

Quantitative CT Imaging

INVITED PERSPECTIVE

Standardization of Quantitative Imaging: The Time Is Right, and ^{18}F-FDG PET/CT Is a Good Place to Start

- "**Success will be achieved when quantitative imaging results are broadly comparable and widely disseminated rather than being possible only in highly selective and controlled environments.**" (Buckler and Boellaard, 2011)

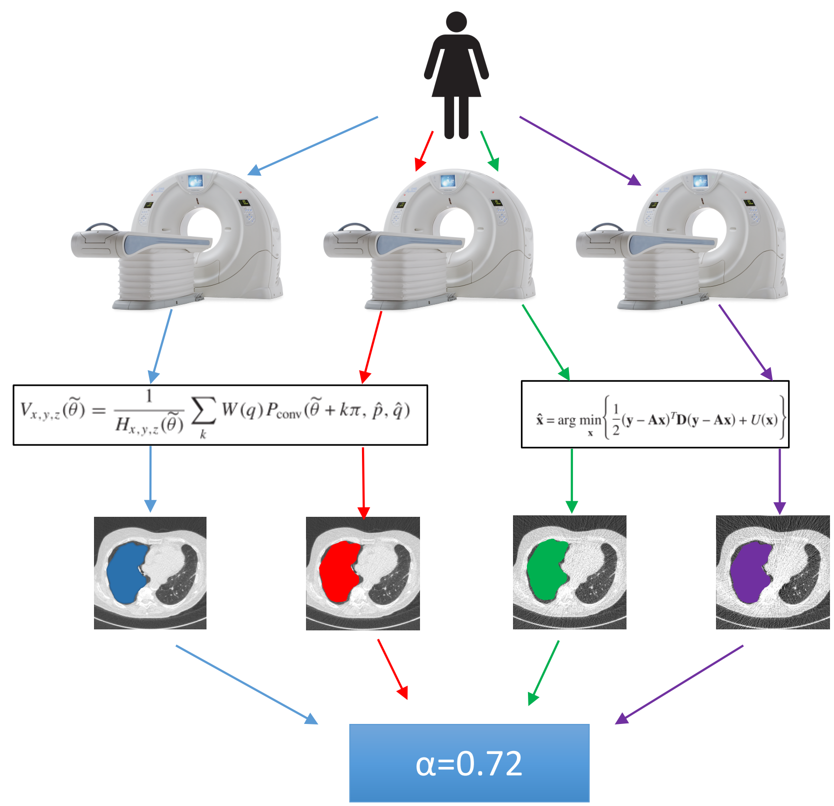
Challenges

Obstacles

1. Heterogeneity
2. Robustness
3. Data

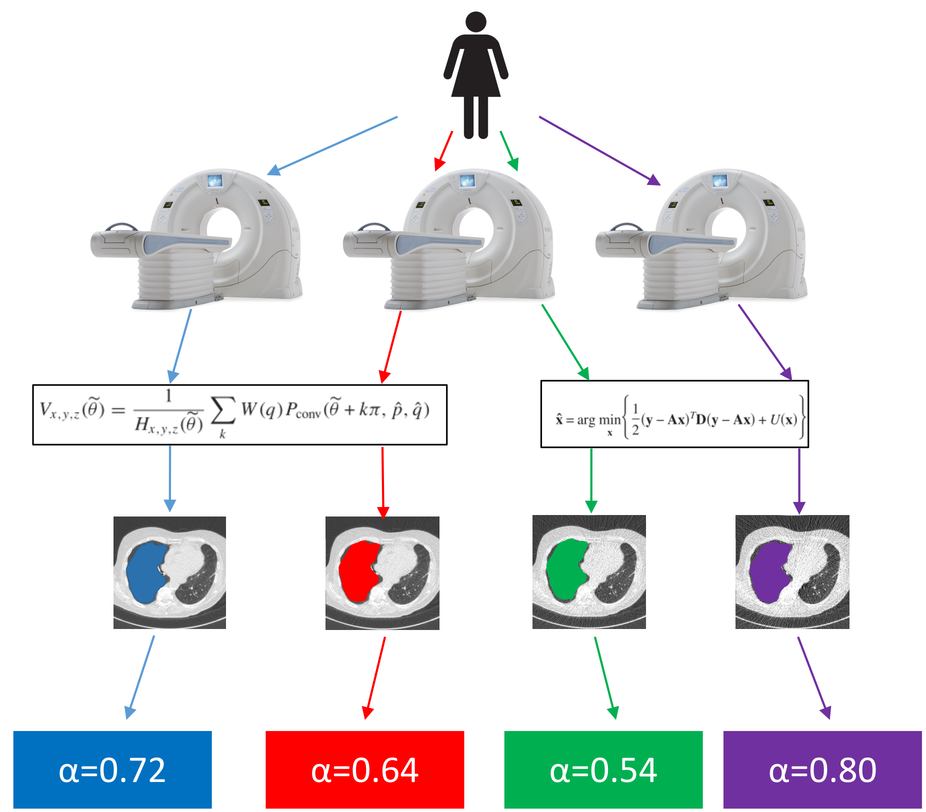
Obstacle 1: Heterogeneity

- Ideal quantitative imaging test would only respond if there is an underlying change in the subject



Obstacle 1: Heterogeneity

- In practice, **how we scan can be as important as what we scan**



Obstacle 1: Heterogeneity

- Sources of variation
  - **Manufacturers** (can't control)
    - Beam spectrum
    - Detectors
    - Reconstruction algorithms
  - **Clinical sites** (could maybe control)
    - Scan protocols (i.e. doses)
    - Reconstruction kernels/iterative strength
    - Slice thickness
    - Patient size, breath-hold, coaching
  - **Quantitative tests** (I don't understand why we can't control)
    - Implementation details

Obstacle 2: Robustness

- Are quantitative imaging tests “stable” under all of that heterogeneity?
- Overlooked in literature

Obstacle 3: Data

- Machine learning
  - Requires *massive* amounts of data
- Public datasets (NSCLC, LIDC, NLST)
  - "Dirty data in, dirty data out"
- Build our own
  - PACS
  - Start from raw data – performing each reconstruction is extremely time consuming

Obstacles

1. Heterogeneity

   Too much!

2. Robustness

   (Nearly) complete lack of

3. Data

   Not enough!

Breakthroughs

Initial Steps

Variability in CT lung-nodule volumetry: Effects of dose reduction and reconstruction methods

Stefano Young,[a] Hyun J. Grace Kim, Moe Moe Ko, War War Ko, Carlos Flores, and Michael F. McNitt-Gray
Department of Radiological Sciences, University of California Los Angeles, Los Angeles, California 90024

The effect of radiation dose reduction on computer-aided detection (CAD) performance in a low-dose lung cancer screening population

Stefano Young,[a] Pechin Lo, Grace Kim, Matthew Brown, John Hoffman, William Hsu, Wasil Wahi-Anwar, Carlos Flores, and Grace Lee
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UCAIR, Department of Radiology, University of Utah, 729 Arapeen Dr, Salt Lake City, Utah 84108, USA

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Initial Steps

- **Needed a better way**
  - Lower experimental "overhead"
    - Time spent reconstructing – 6 months, 1400 reconstructions
    - Evaluation methods
  - Evaluating a much larger range of conditions
    - Dose
    - Reconstruction algorithm
    - Reconstruction settings (e.g. kernel, slice thickness)
    - More subjects
  - Evaluating several (or many) quantitative tests

Breakthroughs

- **Step 1:** Bring the reconstruction out of the clinic into our lab

FreeCT

Technical Note: FreeCT_wFBP: A robust, efficient, open-source implementation of weighted filtered backprojection for helical, fan-beam CT

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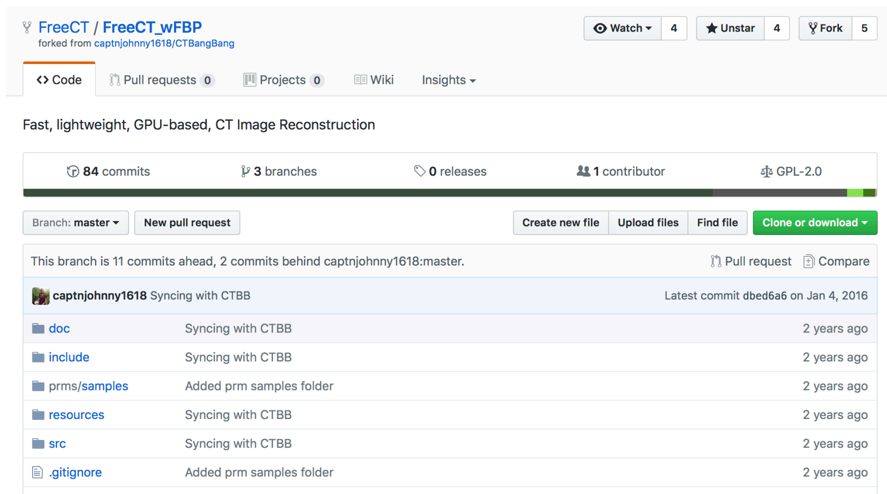

Breakthroughs

FreeCT

- Clinical-quality reconstruction w/o the scanner
- Datasets to get researchers started
- More under development
  - FreeCT_ICD
  - Patient datasets
- Free, open-source (GNU GPL v2.0)

Breakthroughs

- **Step 2:** Operationalize and automate the reconstruction

Breakthroughs

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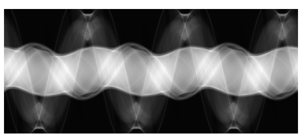

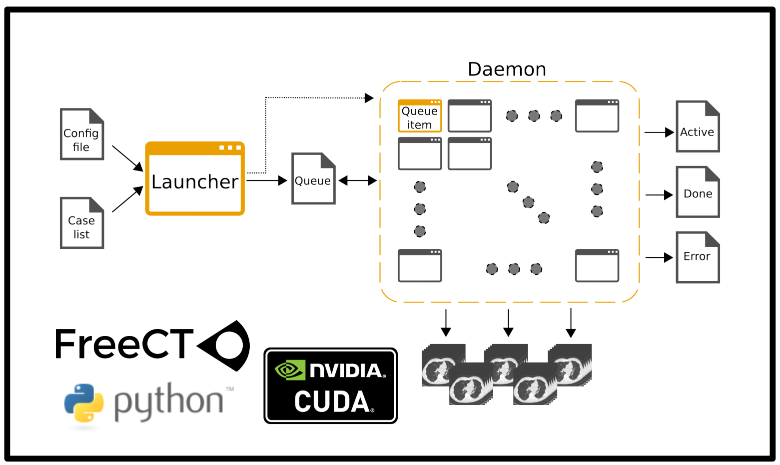

Breakthroughs

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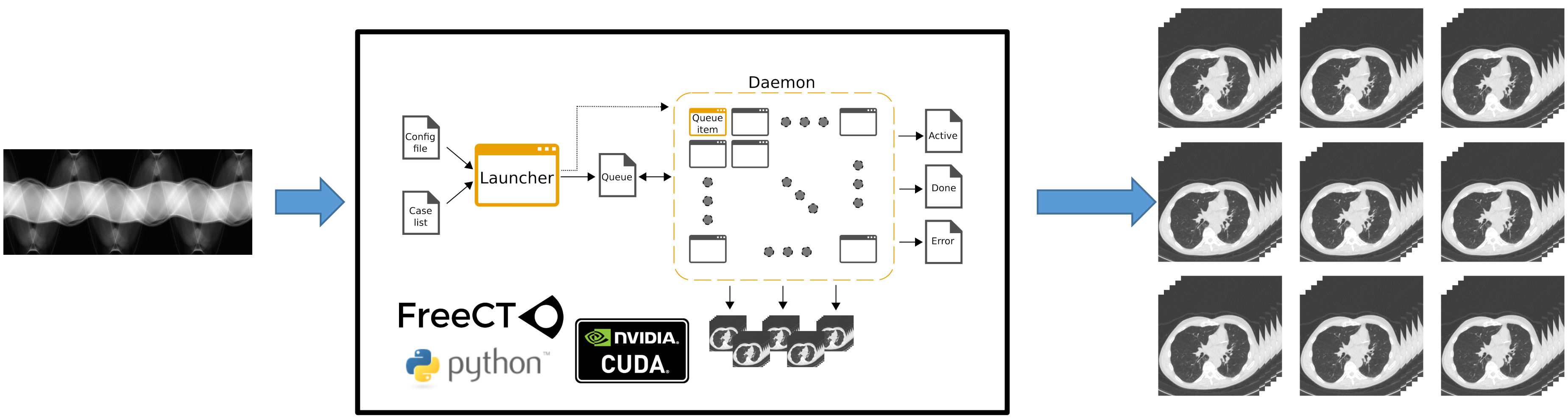

Breakthroughs

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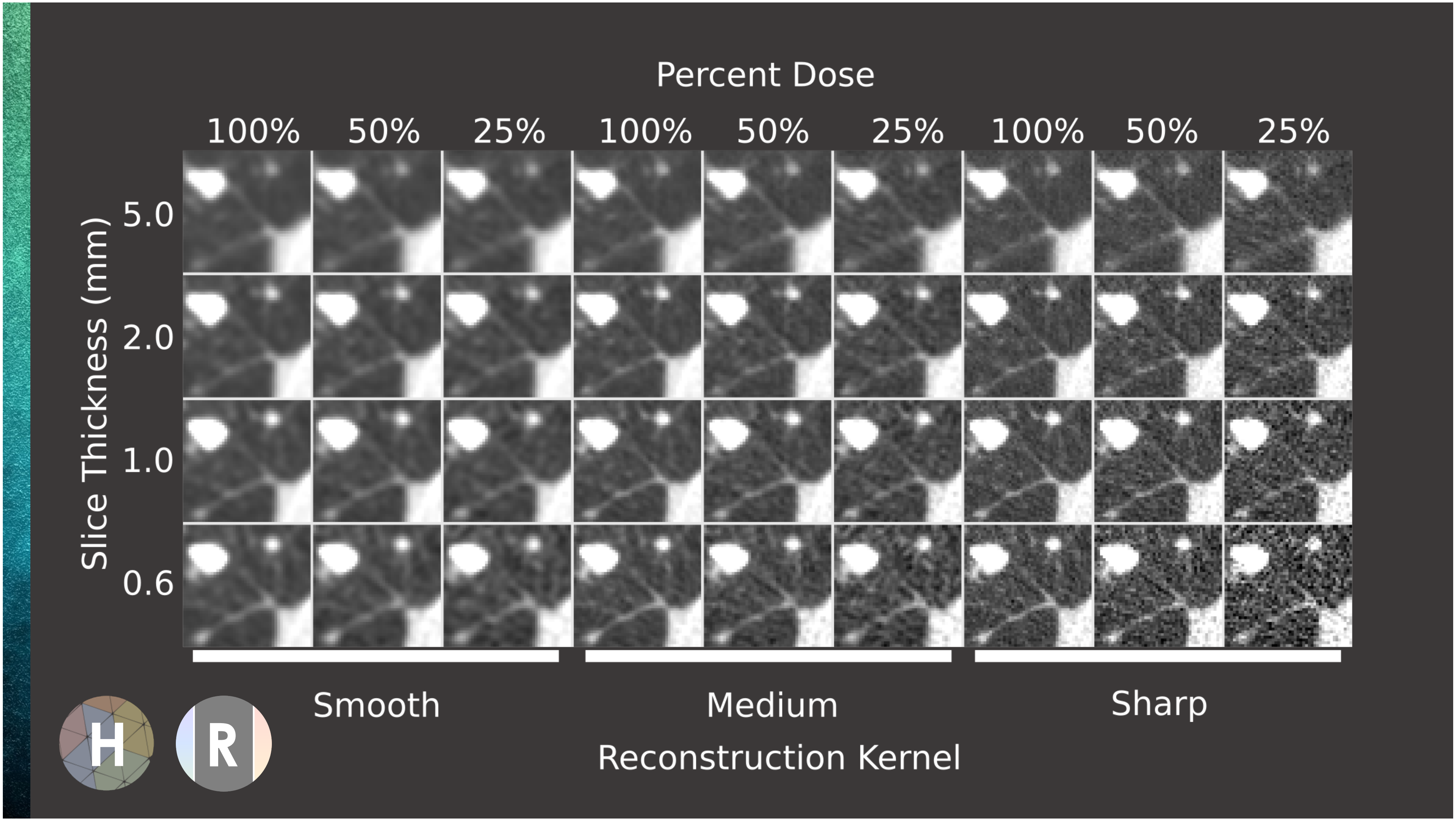
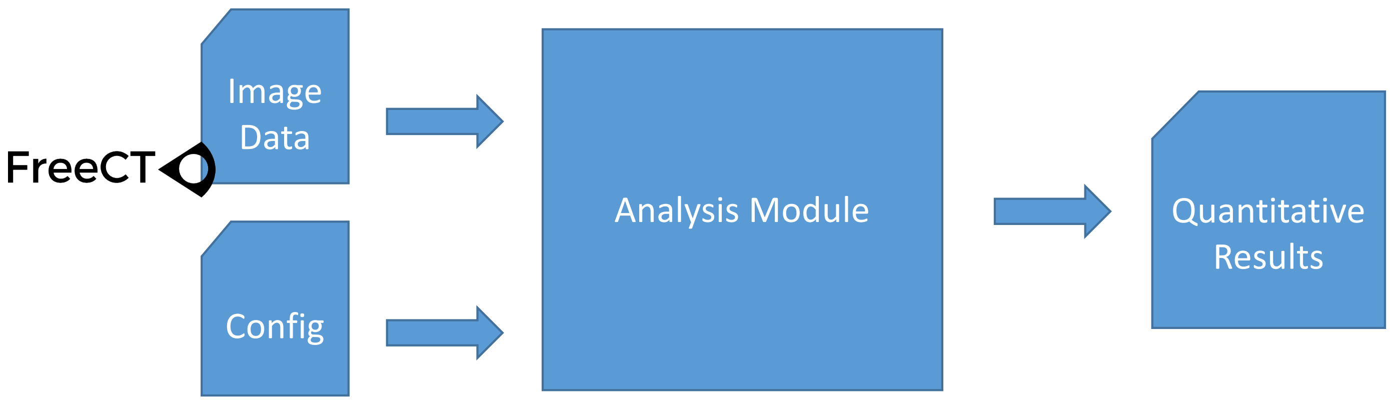


Percent Dose
100%
50%
25%
100%
50%
25%
100%
50%
25%
Slice Thickness (mm)
5.0
2.0
1.0
0.6
Smooth
Medium
Sharp
Reconstruction Kernel

Breakthroughs: The Pipeline

- **Step 3:** Operationalize and automate **analysis**



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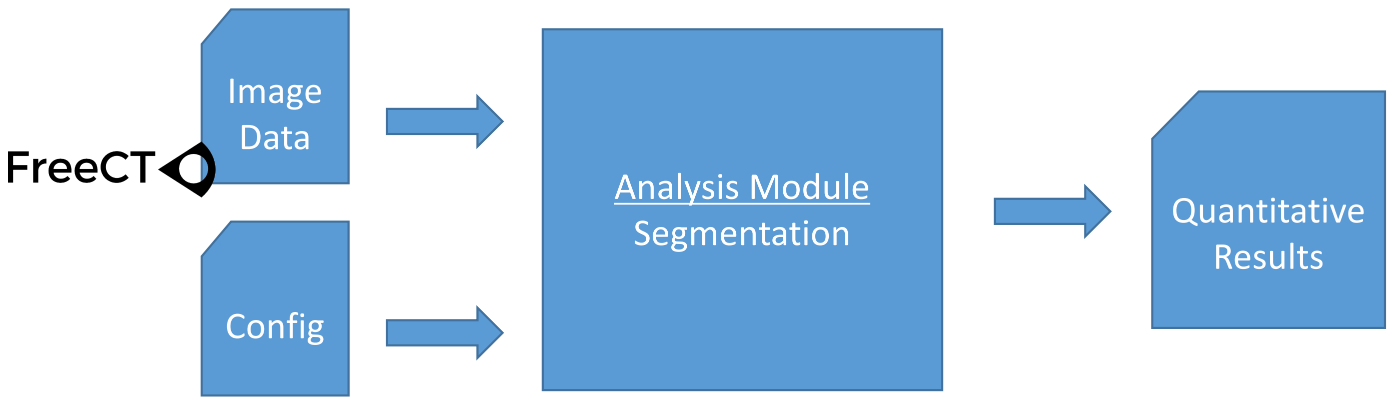

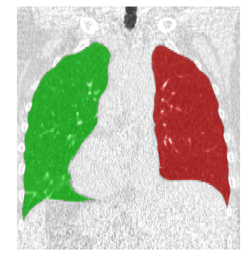

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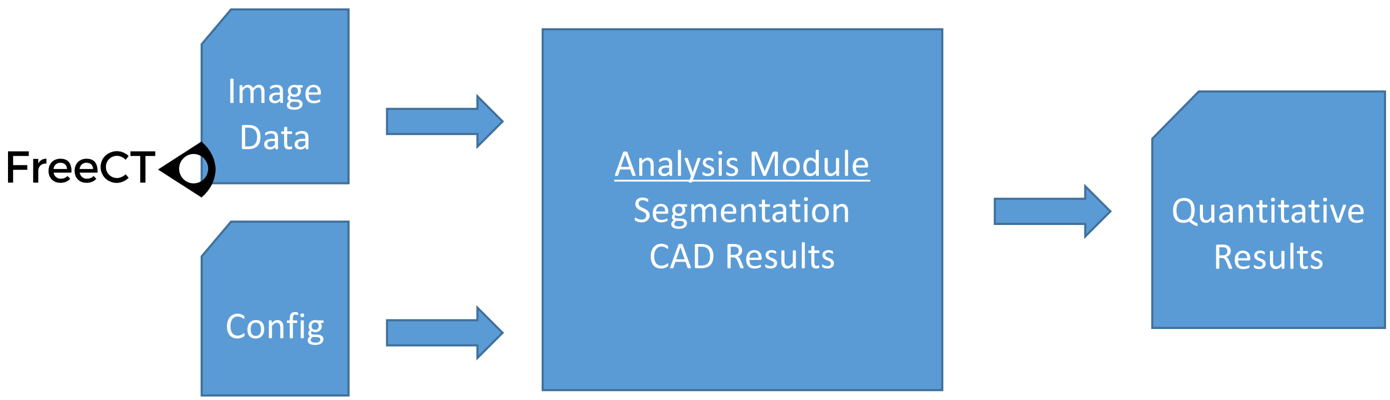

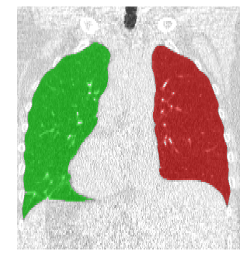

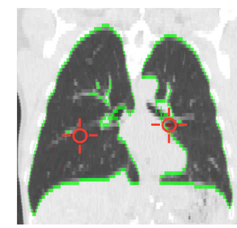

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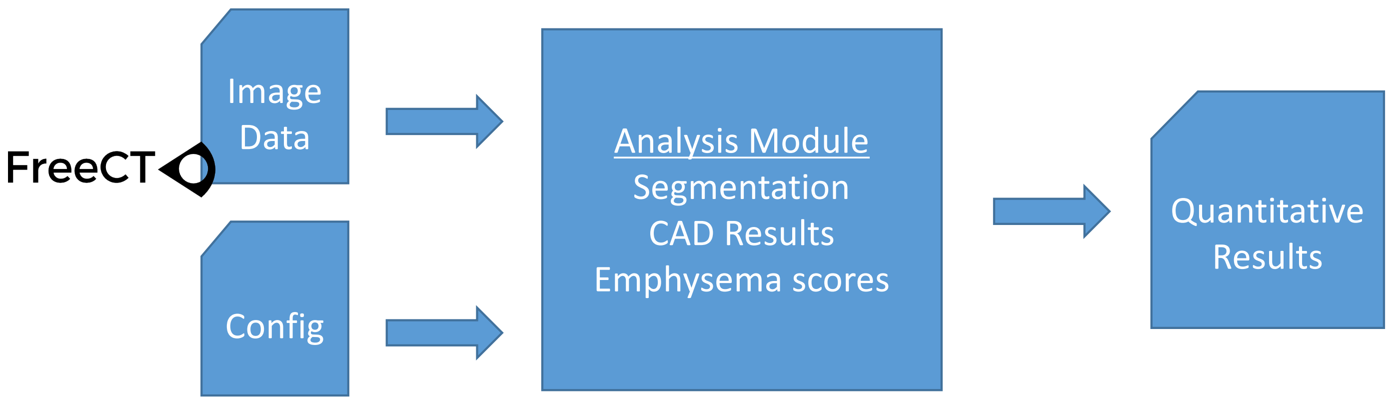

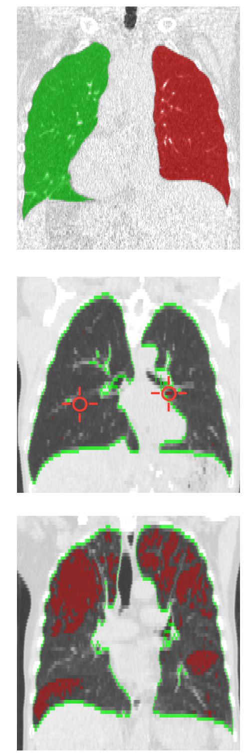

Breakthroughs: The Pipeline

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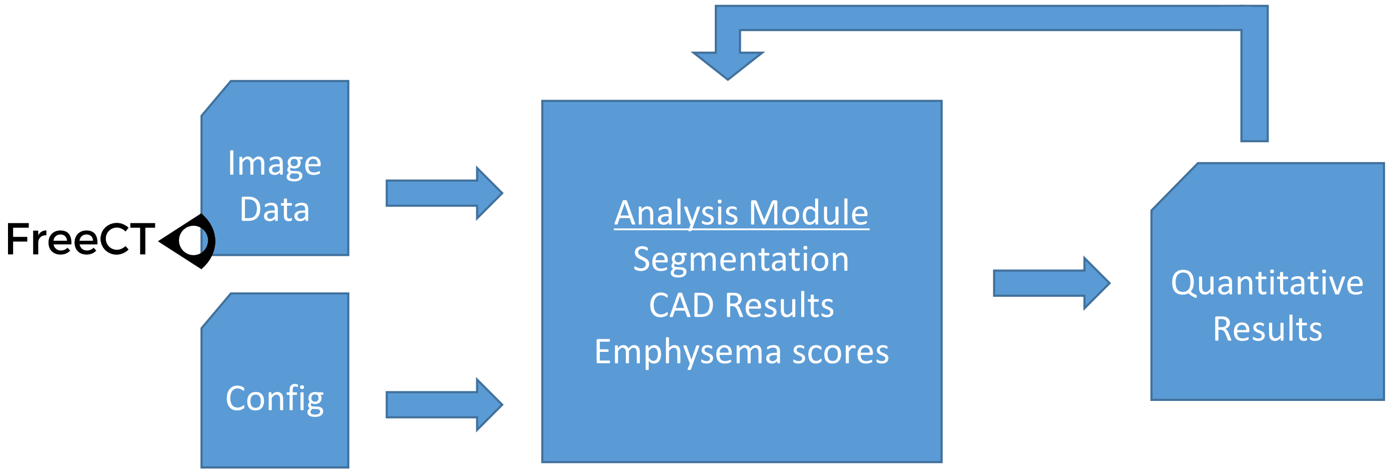
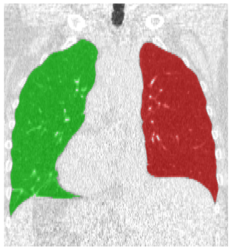
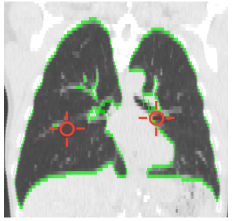
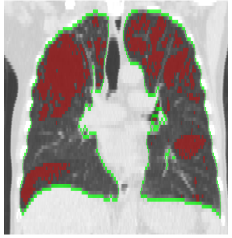


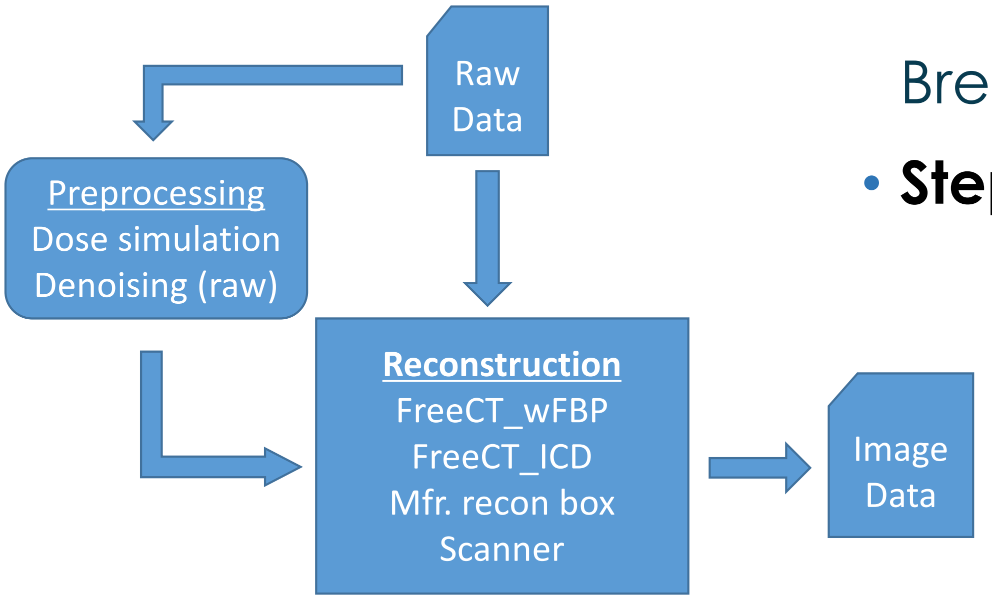






Breakthroughs: The Pipeline

- **Step 4:** Putting it all together



Breakthroughs: The Pipeline

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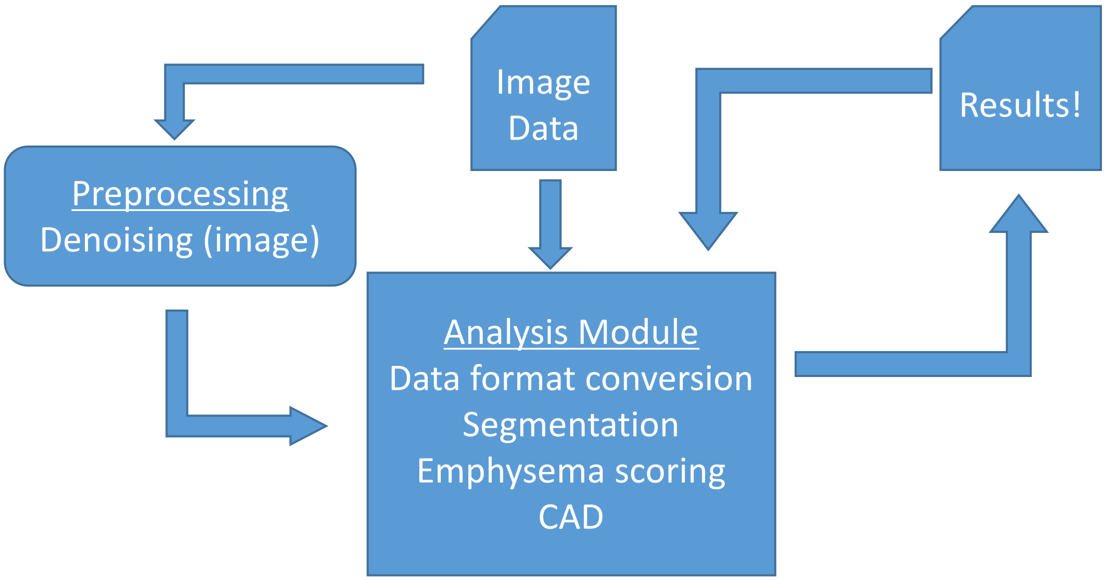

Breakthroughs: The Pipeline

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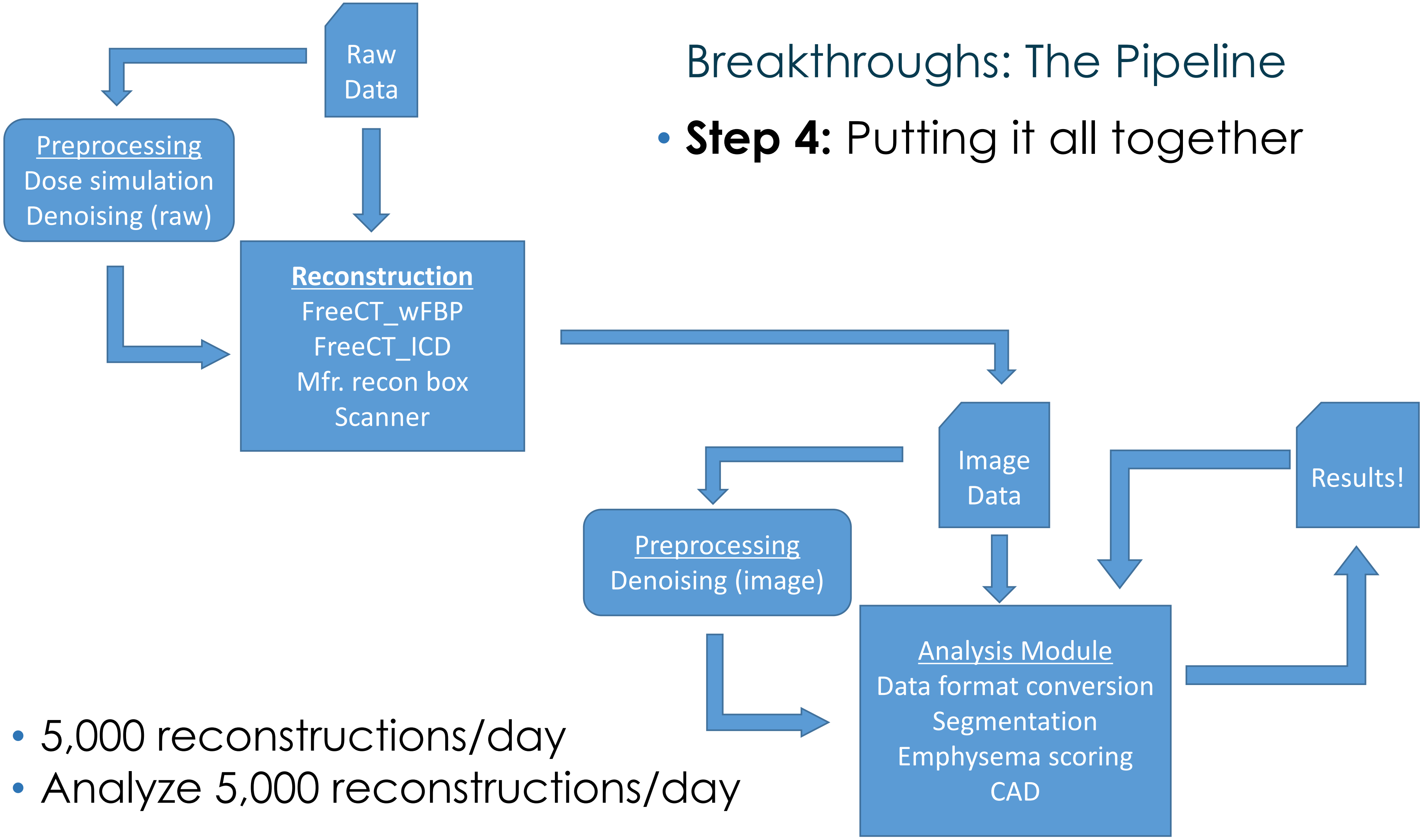

- 5,000 reconstructions/day
- Analyze 5,000 reconstructions/day

Breakthroughs: The Pipeline

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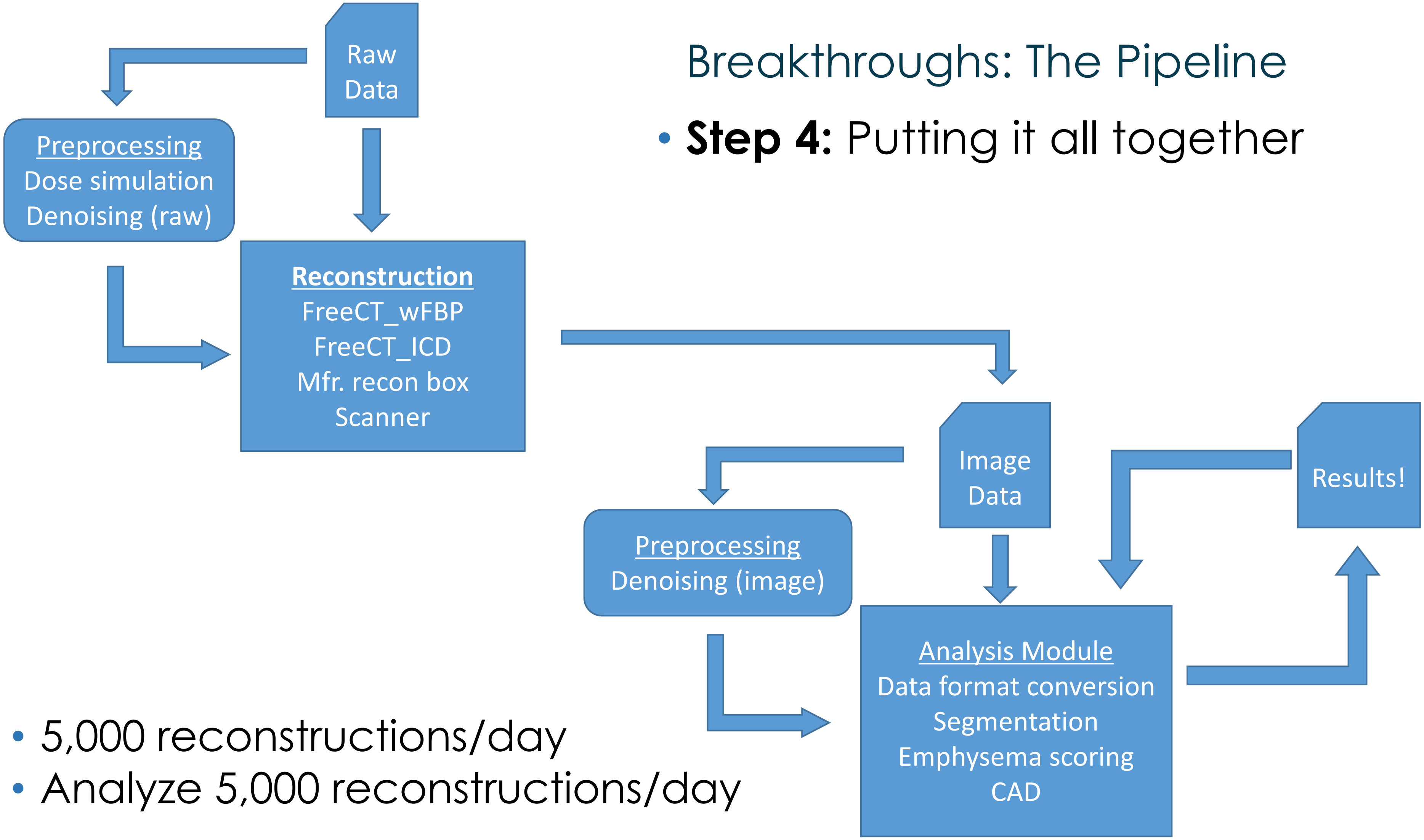
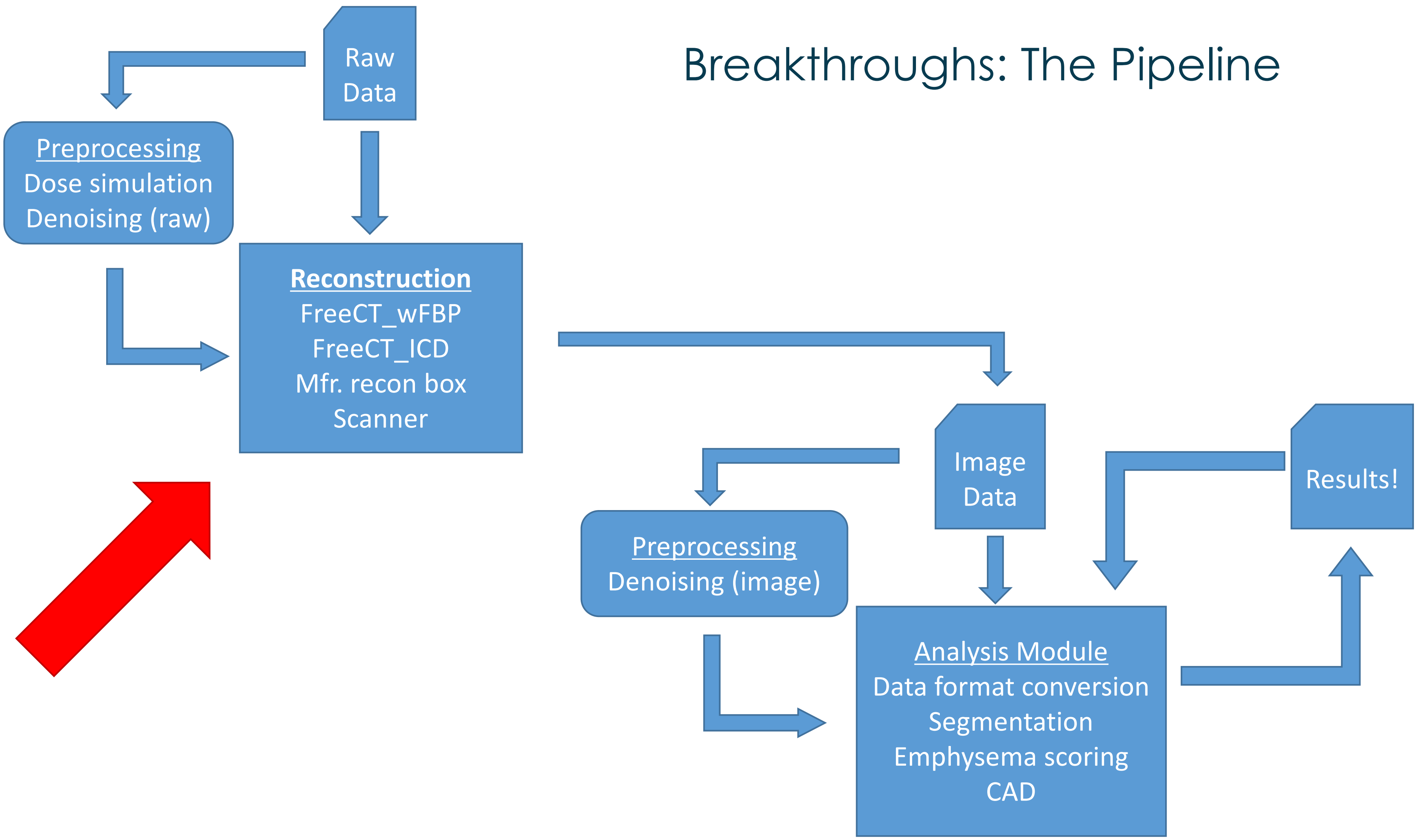


- 5,000 reconstructions/day
- Analyze 5,000 reconstructions/day

Breakthroughs

1. Heterogeneity
   - Pipeline can capture wide range of clinical parameters, patients, conditions, etc.
2. Robustness
   - Pipeline allows efficient, high-throughput testing of QI metrics and techniques
3. Data
   - Pipeline allows generation of large-scale, unique, custom datasets

Breakthroughs: The Pipeline



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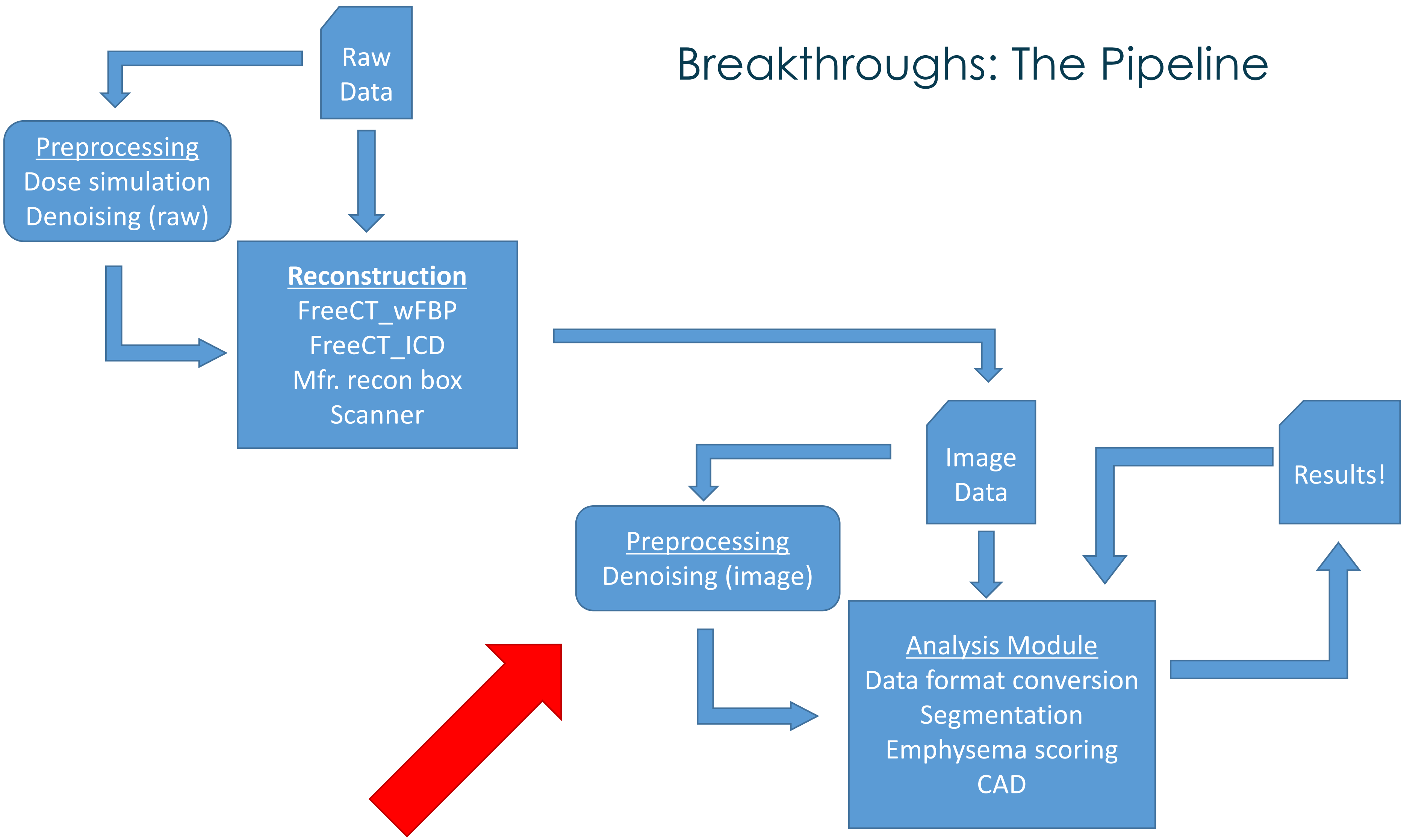
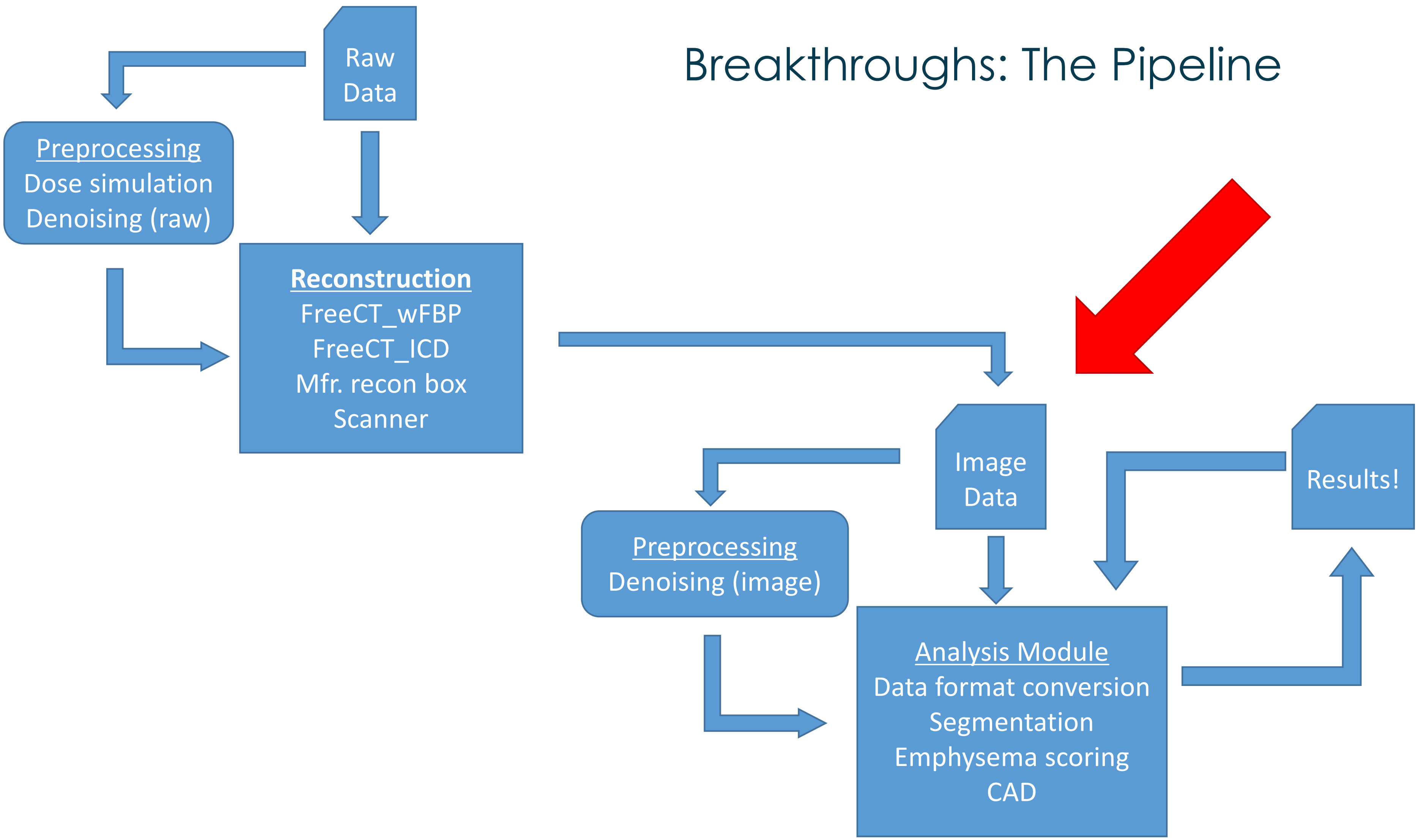


Breakthroughs: The Pipeline



Studies

- Robustness analysis:
  - N Emaminejad, M Wahi-Anwar, J Hoffman, A Sultan, K Ruchalski, G Kim, J Goldin, M Brown, M McNitt-Gray. ***Evaluation of CAD Nodule Detection Performance in Low Dose CT Lung Cancer Screening Across a Range of Dose Levels, Slice Thicknesses and Reconstruction Kernels***. AAPM Annual Meeting. July 31-Aug 3, 2017.
  - J Hoffman, M Wahi-Anwar , N Emaminejad , G Kim , M Brown , M McNitt-Gray. ***A Fully-Automated, High-Throughput, Reconstruction and Analysis Pipeline for Quantitative Imaging in CT***. AAPM Annual Meeting. July 31-Aug 3, 2017.
  - J Hoffman, G Kim, J Goldin, M Brown, M McNitt-Gray. ***A Pilot Study Evaluating the Robustness of Density Mask Scoring (RA-950), a Quantitative Measure of Chronic Obstructive Pulmonary Disease, to CT Parameter Selection Using a High-Throughput, Automated, Computational Research Pipeline***. AAPM Annual Meeting. July 31-Aug 3, 2017.
- Data generation:
  - Hoffman, J. M., Noo, F., Mcmillan, K., Young, S., & McNitt-Gray, M. ***Assessing nodule detection on lung cancer screening CT: the effects of tube current modulation and model observer selection on detectability maps***. In *Proc. SPIE Medical Imaging,* 2016.
  - *Hoffman, J.*, Noo, F., McNitt-Gray, M. ***Influence of Tube Current Modulation on Noise Statistics of Reconstructed Images in Low-Dose Lung Cancer CT Screening***. American Association of Physicists in Medicine 2017. Annual Meeting and Exhibition, July 30-August 3, 2017, Denver CO.
- Test platform
  - T Zhao, J Hoffman, M McNitt-Gray, D Ruan. ***Low-Dose CT Image Denoising Using An Optimized Wiener Filter in the BM3D Algorithm.*** AAPM Annual Meeting. July 31-Aug 3, 2017.

Conclusion

Conclusions

Thinking **bigger**

Thank you! Questions?

UCLA Health

Quantitative CT Imaging

- First patient scan in 1971
- First attempts at quantitative imaging by the mid-1970s
  - Isherwood et al. - "Bone-Mineral Estimation By Computer-Assisted Transverse Axial Tomography" 1976
- Attempts to translate to lung by late 1980s
  - Müller et al. – "Density Mask: An Objective Method to Quantitate Emphysema Using Computed Tomography" 1988

- 30+ years of work on quantitative imaging and it's largely* unused clinically

Why No Clinical QCT?

- Quantitative CT “feels” generally untrustworthy
- No one is quite sure that they can reproduce studies in the literature
- If results are reproducible, are they comparable across sites and studies?

Quantitative CT Imaging

Management of COPD: Is there a role for quantitative imaging?

Miranda Kirby (PhD)[a,b], Edwin J.R. van Beek (MD PhD)[c], Joon Beom Seo (MD PhD)[d], Juergen Biederer (MD)[e,f,g], Yasutaka Nakano (MD PhD)[h], Harvey O. Coxson (PhD)[a,b], Grace Parraga (PhD)[i,j,*]

- "Despite the advances in imaging methods and measurements, the road towards precision medicine in COPD is still long and **will require the standardization of imaging protocols and methods**, development and validation of imaging biomarkers, and demonstrating efficacy in clinical trials." (Kirby et al. 2016)

Quantitative CT Imaging

- In addition to older approaches, we now have:
  - Perfusion, volumetry, etc.
  - Computer Automated Detection/Diagnosis (CAD)
    - Mammography: Late 80s, early 90s (Chan et al.)
    - Lung nodules: Brown et al. “Towards a clinically usable CAD…”
  - Radiomics
    - Mining of quantitative data from images and attempt to correlate with underlying disease or gene expression
    - Aerts et al.: “Decoding Tumor Phenotype by Noninvasive Imaging Using a Quantitative Radiomics Approach”

Quantitative CT Imaging

- And yet, despite dozens (maybe hundreds) of publications, we see very little day-to-day usage of quantitative imaging with CT
  - CAD for mammography
  - CVIB just obtained grant to develop quantitative CT "report" to include with lung screening, HOWEVER, makes crude classifications (none, mild, medium, severe)
  - … Why?

Solutions

- Robustness evaluation - a **critical** component of every proposed quantitative imaging test
  - Check the performance of our test on a wide range of clinical imaging conditions to determine whether performance is maintained
- First we concede that heterogeneity isn't going anywhere
  - Manufacturers
  - Radiologist preferences
  - Mistakes
- Even with rigorous standardization, it's not 100% clear that everything researchers want to do is possible
  - Evidence suggests that it may be possible, but no definitive answers

Conclusions

- Introduced a modular, quantitative image data generation and analysis framework, “the pipeline”
- Pipeline will help start to close gaps that make people uncomfortable with QI in CT
- Pipeline’s flexibility also make it uniquely suited for other applications
  - Deep learning
  - Evaluation of new technologies
  - Open source