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CT Clinical Innovation Center

Low Dose CT Grand Challenge

Cynthia McCollough, PhD
CT Clinical Innovation Center, Department of Radiology
Mayo Clinic, Rochester, MN

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On behalf of our team at Mayo Clinic

- Co-leaders
  - JG Fletcher, MD
  - Lifeng Yu, PhD
  - Shuai Leng, PhD
  - Rickey Carter, PhD
  - David Holmes III, PhD
- Trainees
  - Baiyu Chen, PhD
  - Kyle McMillan, PhD
  - Chi Ma, PhD
- Staff
  - Tammy Drees
  - Greg Michalak, PhD
  - Alice Huang
  - Kris Nunez
  - Shane Dirks

With special thanks to Farhana Khan of AAPM headquarters staff

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LOW Dose CT Grand Challenge

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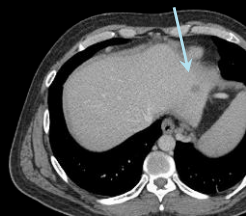
Come find me at a lower dose

- **Image reconstruction and denoising experts**
  - Test your algorithm against others in the field
- **Using real patient projection data**
  - In vendor-neutral format
  - w/ and w/o pathology
- **Winners announced at AAPM 2016**
  - Free meeting registration
  - Participation in a low dose CT session
  - Manuscript co-authorship



www.aapm.org/GrandChallenge/LowDoseCT

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Radiologist Interpretation

- Host site provided radiologist interpretation of twenty test cases
- Reader pool was composed of senior residents, fellows, and faculty.
- No reader read the same case twice.
- Cases from any given participant were dispersed among readers so as to minimize the impact of reader bias on any one participant.
- A standardized reading tool was used for marking of the lesions.
- Rigorous reader training was performed to ensure consistent marking between readers.
- For each case, the radiologist was required to mark the location of any detected metastasis, or to grade the case as normal if no lesions are detected.

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Reading design

- Given the time constraints and the high potential of recall (e.g., 20 cases shown repeatedly with limited washout time), we designed a Latin squares reading framework.
- Design assumes that readers will be exchangeable in performance. Differences in individual reader performance is assumed to be distributed uniformly across participants.

Readers \ Patient Cases	C1	C2	...	Cc
R1	P1	Pp	...	P2
R2	P2	P1	...	Pp
...	...	...	...	...
Rr	Pp	P2	...	P1

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Scoring

- Reader lesion markings (or notation of case as normal) were compared to reference standard for each case and data scored on a per lesion and per case basis.
- Reader markings were considered correct if the location marked as center of the lesion fell anywhere within the true lesion's boundaries.
- Per lesion scoring (included penalty for false positive and negative markings):
  - +1 for true positive marking of a lesion (correctly marking a lesion)
  - -1 for false positive marking of a lesion (no lesion exists at that location)
  - -1 for false negative (a lesion exists that was not marked)
- Per case scoring (included penalty for false positive and negative markings):
  - +1 for true negative case (no lesions marked in a case with no lesions)
  - +1 for true positive case (at least one lesion was correctly marked in a case with lesions)
  - -1 for false negative (no lesions marked in a case that had lesions)
  - -1 for false positive (at least one lesion marked in a case with no lesions)

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Scoring

- Per lesion normalized score
  (NS) = per lesion score / total number of lesions x 100%
- Per case normalized score
  (NS) = per case score / 20 X 100%
- False positive and false negative markings could result in a negative score
- Overall performance score was calculated as:

  [[per lesion NS] + [per case NS]] ÷ 2
- In the event of a tie, JAFROC figure of merit (AUC), which takes into account reader confidence, was used.

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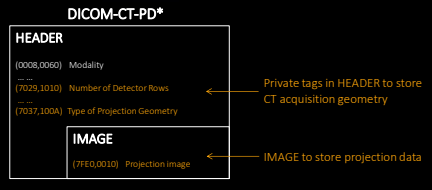
Library of patient CT projection data

- The library
  - stores projection data in an open and standardized format



*Chen et al., "Development and validation of an open data format for CT projection data" Med Phys. **42**.6964 (2015).

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Library of patient CT projection data

- The library
  - stores projection data in an open and standardized format
  - includes scans of various types
    - Routine non-contrast head exams
    - Low dose non-contrast chest exams for lung nodule screening
    - Routine contrast-enhanced abdomen exams

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    - Low dose chest exams for lung nodule screening
    - Routine contrast-enhanced abdomen exams
    - Gated exams
    - Dual-energy exams
  - includes a wide range of patients and pathologies

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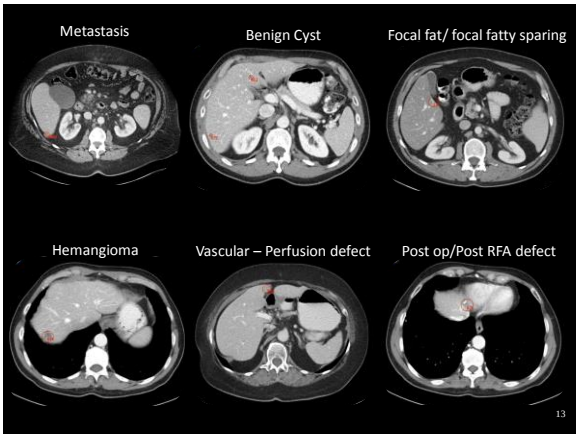

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Library of patient CT projection data

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  - stores projection data in an open and standardized format
  - includes scans of various types
    - Routine head exams
    - Low dose chest exams for lung nodule screening
    - Routine contrast-enhanced abdomen exams
    - Gated exams
    - Dual-energy exams
  - includes a wide range of patients and pathologies
  - includes various radiation dose levels
    - Clinical/regular dose levels
    - Reduced dose levels (simulated via noise insertion*)

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*Yu et al., "Development and validation of a practical lower-dose-simulation tool for optimizing computed tomography scan protocols," J Comput Assist Tomogr. (2012).

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Cases shared

- 10 training patient cases + ACR CT Phantom scan
  - Projection and all image data sets, full and low dose
    - 1 and 3 mm thick images
    - B30 and D45 reconstruction kernels
- 20 test patient cases + ACR CT Phantom scan
  - Projection or one image data set, low dose only

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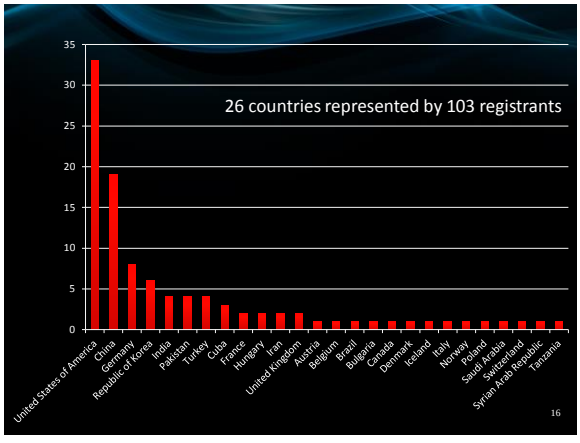

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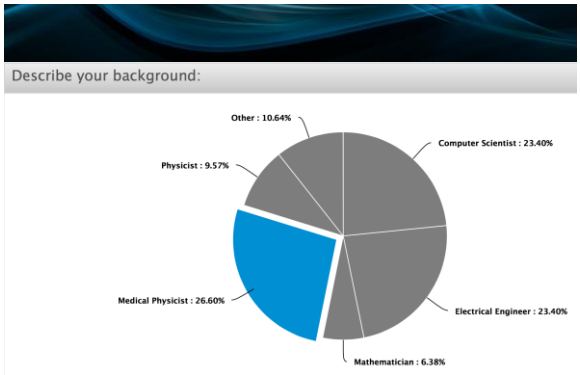

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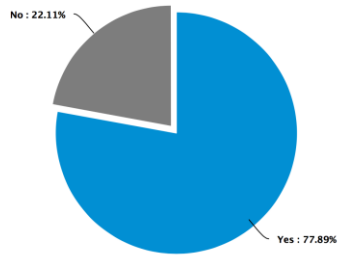
Have you previously worked with medical CT data sets?



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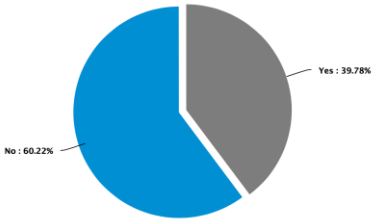
Have you previously collaborated with a radiologist regarding optimization of your algorithm for medical diagnostic applications?



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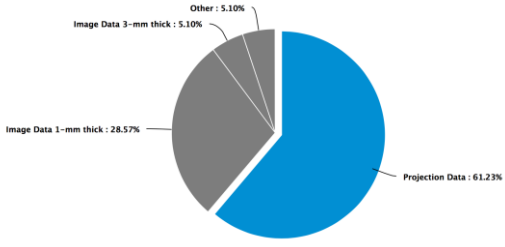
What type of data does your algorithm require?



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Participation

- 103 registrants
- 90 unique sites
- 77 data sharing agreements
- 41 downloads of test data
- 22 sites returned
- 20 interpretable sites

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PI Name	Institute	Country
Licheng Cheng	Shanghai United Imaging Healthcare Co, Ltd.	China
Yang Chen	Southeast University	China
Xuanqin Mou	Xi'an Jiaotong University	China
Wei Liu	Xidian University	China
Miao Wang	Xidian University	China
Linlin Chen	Xidian University	China
David Hansen	Aarhus University Hospital	Denmark
Oliver Taubmann	Friedrich-Alexander-University Erlangen-Nuremberg	Germany
Felix Kopp	Technische Universitat Munchen	Germany
Sebastian Allner	Biomedical Physics TUM	Germany
Zsolt Balogh	Budapest Business School	Hungary
Bjorgheidur Helgadottir	Raforninn/Image Owl	Iceland
Nam-Yong Lee	Inje University	Republic of Korea
Eunhee Kang	KAIST	Republic of Korea
Sunhee Wi	KAIST	Republic of Korea
Nghia Vo	Diamond Light Source	United Kingdom
Larry Zeng	University of Utah	US
Cristian Badea	Duke University	US
Kyungsang Kim	Massachusetts General Hospital	US
Joshua Trzasko	Mayo Clinic	US
Ashvin George	Instarecon Inc	US
Dan Ruan	UCLA	US

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Results

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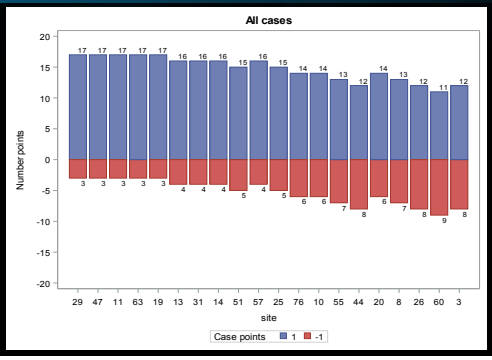
Overall case performance



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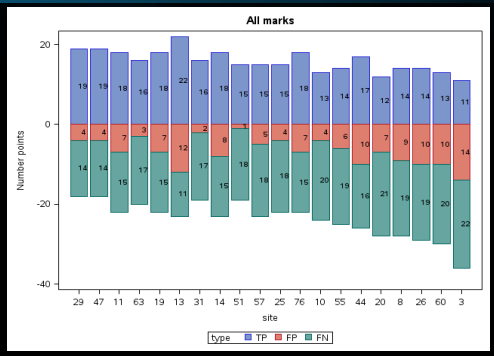
Detection rates by site



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Numerical Results

Rank	Site	Lesion points	Norm. lesion score	Case points	Norm. case score	Total score	AUC	
1	29	1	0.03030	14	0.7	0.3652	0.784	US
2	47	1	0.03030	14	0.7	0.3652	0.746	Korea
3	11	-4	-0.12121	14	0.7	0.2894	0.779	US
4	63	-4	-0.12121	14	0.7	0.2894	0.751	
5	19	-4	-0.12121	14	0.7	0.2894	0.711	
6	13	-1	-0.03030	12	0.6	0.2848	0.730	
7	31	-3	-0.09091	12	0.6	0.2545	0.765	
8	14	-5	-0.15152	12	0.6	0.2242	0.717	
9	51	-4	-0.12121	10	0.5	0.1894	0.763	
10	57	-8	-0.24242	12	0.6	0.1788	0.696	
11	25	-7	-0.21212	10	0.5	0.1439	0.746	
12	76	-4	-0.12121	8	0.4	0.1394	0.747	
13	10	-11	-0.33333	8	0.4	0.0333	0.687	
14	55	-11	-0.33333	6	0.3	-.0167	0.662	
15	44	-9	-0.27273	4	0.2	-.0364	0.631	
16	20	-16	-0.48485	8	0.4	-.0424	0.600	
17	8	-14	-0.42424	6	0.3	-.0621	0.611	
18	26	-15	-0.45455	4	0.2	-.1273	0.632	
19	60	-17	-0.51515	2	0.1	-.2076	0.635	
20	3	-25	-0.75758	4	0.2	-.2788	0.532	

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Source data types

Projection -10
3 mm D45 - 1
3 mm B30 - 3
1 mm D45 - 1
1 mm B30 - 5

Rank	Site #	Data type
1	29	Projection
2	47	Projection
3	11	3 mm D45
4	63	3mm B30
5	19	1 mm D45
6	13	Projection
7	31	3 mm B30
8	14	1 mm B30
9	51	1 mm B30
10	57	Projection
11	25	1 mm B30
12	76	1 mm B30
13	10	Projection
14	55	1 mm B30
15	44	Projection
16	20	Projection
17	8	Projection
18	26	Projection
19	60	3mm B30
20	3	Projection

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← 100% dose

What range of performance was observed at 25% dose?

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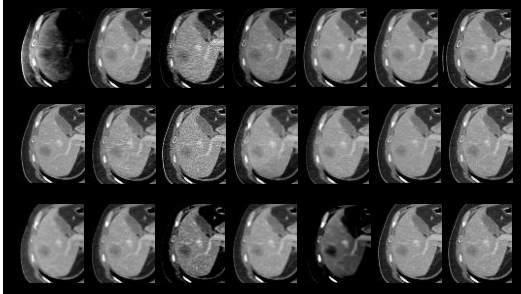

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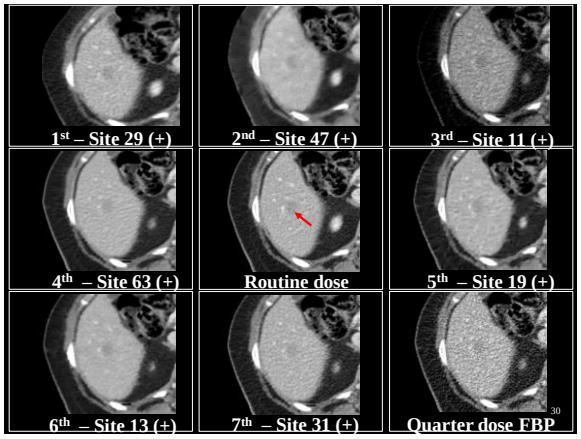
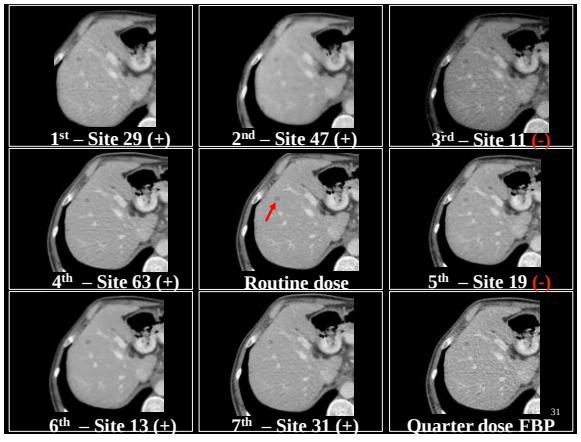
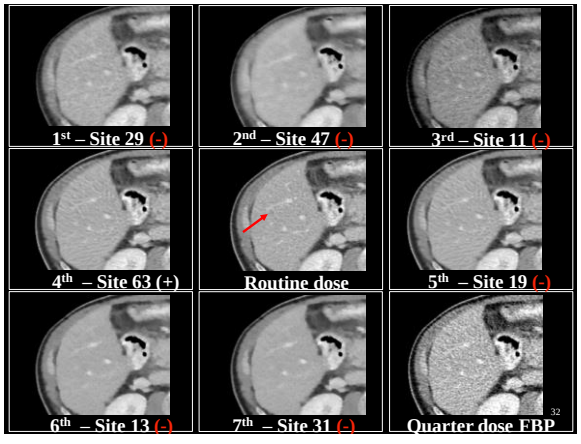
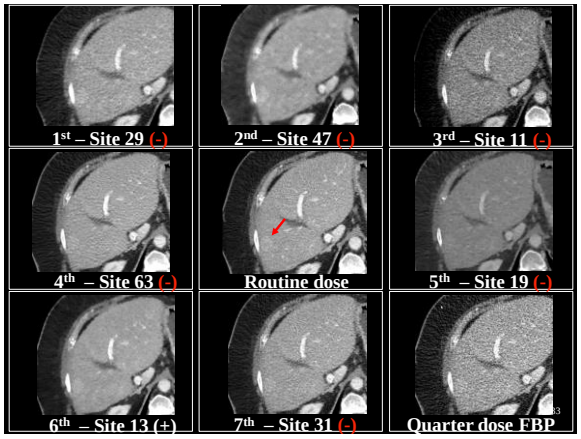

1st – Site 29 (+)
2nd – Site 47 (+)
3rd – Site 11 (+)
4th – Site 63 (+)
Routine dose
5th – Site 19 (+)
6th – Site 13 (+)
7th – Site 31 (+)
Quarter dose FBP
30


1st – Site 29 (+)
2nd – Site 47 (+)
3rd – Site 11 (-)
4th – Site 63 (+)
Routine dose
5th – Site 19 (-)
6th – Site 13 (+)
7th – Site 31 (+)
Quarter dose FBP
31


1st – Site 29 (-)
2nd – Site 47 (-)
3rd – Site 11 (-)
4th – Site 63 (+)
Routine dose
5th – Site 19 (-)
6th – Site 13 (-)
7th – Site 31 (-)
Quarter dose FBP
32


1st – Site 29 (-)
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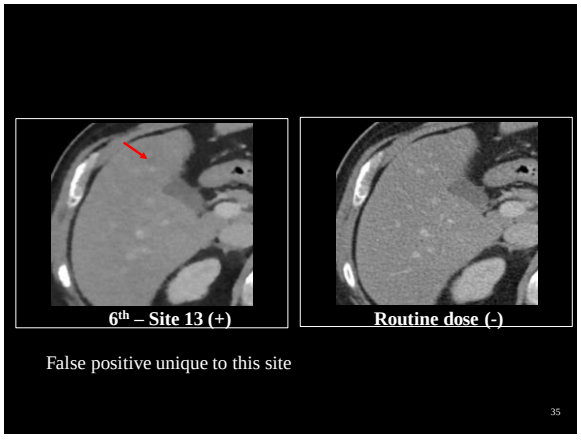
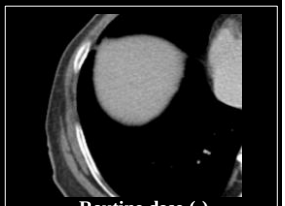
3rd – Site 11 (-)
4th – Site 63 (-)
Routine dose
5th – Site 19 (-)
6th – Site 13 (+)
7th – Site 31 (-)
Quarter dose FBP


6th – Site 13 (+)
Routine dose (-)
False positive unique to this site
34


6th – Site 13 (+)
Routine dose (-)
False positive unique to this site
35

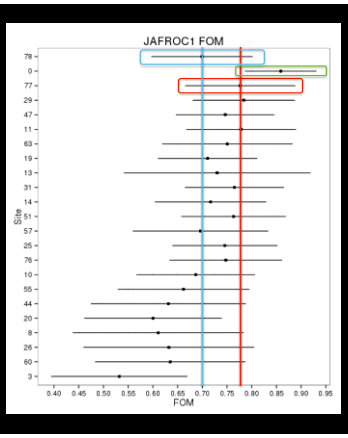
2nd – Site 47 (+)



Routine dose (-)

False positive unique to this site

36



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Future work

- Evaluate demographic data, looks for trends
  - Image domain vs projection domain data
  - Algorithm processing speed
  - Who worked with a radiologist
  - Etc.
- Evaluate top performers with full MRMC study design
  - Validate the pseudo observer approach used with full MRMC study
- Evaluate phantom data to predict MRMC results
  - Are there unique properties or "looks" that did best

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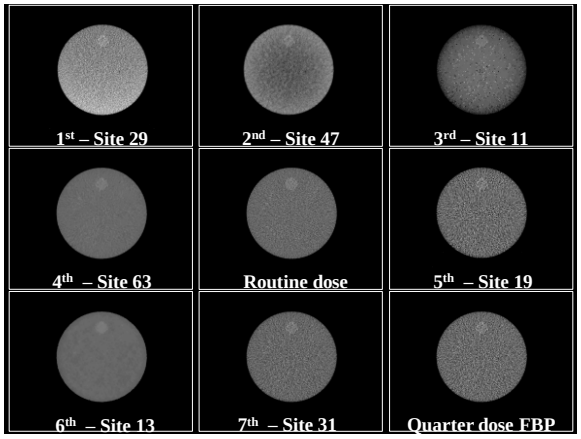

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And the Winners are …

- 3rd – Dr. Larry Zeng, Professor of Engineering at Weber State University in Ogden, Utah
- 2nd - Eunhee Kang, PhD student at the Korea Advanced Institute of Science and Technology in South Korea, her colleague, Junhong Min, and her advisor, Dr. Jong Chul Ye .
  - Dr. Ye will be presenting
- 1st - Dr. Kyungsang Kim, post-doctoral research fellow at Massachusetts General Hospital in Boston, Massachusetts, and his advisor, Dr. Quanzheng Li.
  - Dr. Kim will be presenting

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