Fast, near real-time, Monte Carlo dose calculations using GPU

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Outline

- GPU Monte Carlo
- Clinical Applications
- Conclusions

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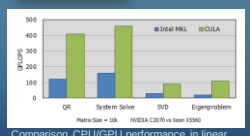
GPU

- A specialized accelerator (personal super-computer)

Comparison CPU/GPU peak processing power



Comparison CPU/GPU performance in linear algebra solver

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GPU

- Advantages
  - High processing power: 3-4 TFLOPS per card nowadays
  - Low cost: order of magnitude lower than CPU with similar processing power
  - Easy to set up, maintain, and access
  - Full system control: do not rely on 3rd party management
  - Low burden of data communication: card is local at the computer
- Suitable for Medical Physics problems

  Jia et. al. Review Article, *PMB*, **59**, R151(2014)

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GPU Monte Carlo project

- Since 2009 in UCSD
- Utilize GPU to accelerate MC simulations in medical physics
  - Use appropriate physics model to maintain accuracy
  - Design GPU-friendly implementations for high efficiency
- Apply developed codes to solve medical physics problems

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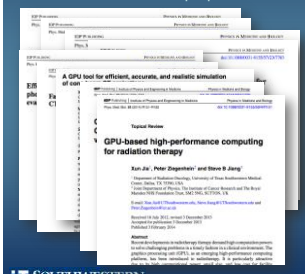
GPU Monte Carlo project

- Published >10 papers on peer-reviewed journals, with 6 more under review/in preparation, and >20 conference presentations



- Four GPU training courses
  - Upcoming 5th one in Oct 2014 at UTSW

GPU Monte Carlo project

- A wide spectrum of GPU-based MC packages
  - gDPM: MV photon/electron (2009)
  - gMCDRR/gCTD: kV photon (2011)
  - gPMC: proton (+electron) (2012)
  - gBMC: brachytherapy dose calculations (2014)
  - g????: MV photon/electron, openCL (2014)
  - ……
- Developing new GPU packages
- Unifying code interface
- Solve clinical problems

gDPM

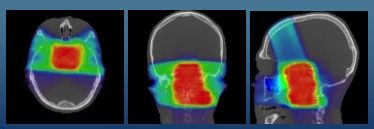
- gDPM
  - Maintain DPM physics and hence accuracy
  - Seek for optimal implementation and high efficiency

Jia et. al., *Phys. Med. Biol.*, **55**, 3077 (2010)
Jia et. al., *Phys. Med. Biol.*, **56**, 7107 (2011)

- Phase space source model with GPU-friendly implementation

Townson et. al., *Phys. Med. Biol.*, **58**, 4341(2013)

- Results



gDPM

- Average relative uncertainty, t-statistical test passing rate, execution time T, and speed-up factor

Source type	# of Histories	Case	$\langle \sigma_D/D \rangle$ (%)	P_{all} (%)	T_{CPU} (sec)	T_{GPU} (sec)	T_{CPU}/T_{GPU}
20MeV e	2.5×10^6	water-lung-water	0.98	99.9	117.5	1.71	69.7
20MeV e	2.5×10^6	water-bone-water	0.99	99.8	127.0	1.65	77.0
6MV p	2.5×10^8	water-lung-water	0.72	97.7	1403.7	16.1	87.2
6MV p	2.5×10^8	water-bone-water	0.64	97.5	1741.0	20.5	84.9
6MV p	2.5×10^8	VMAT Prostate patient	0.78	N/A	N/A	39.6	N/A
6MV p	2.5×10^8	IMRT HN patient	0.57	N/A	N/A	36.1	N/A

CPU: Intel Xeon processor with 2.27GHz
GPU: NVIDIA Tesla C2050

- Multi-GPU

Source type	# of Histories	Case	T_{GPU} (sec)	T_{4GPU} (sec)	T_{GPU}/T_{4GPU}
6MV Photon	4×10^9	water-lung-water	312.82	78.4	3.99
6MV Photon	4×10^9	water-bone-water	403.75	101.19	3.99

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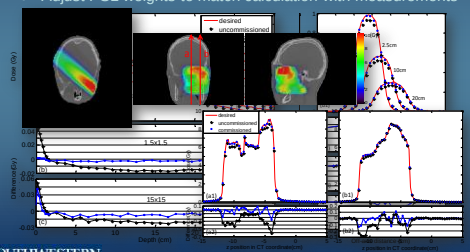
gDPM

- Automatic commissioning
  - Phase spacelet (PSL)
  - Adjust PSL weights to match calculation with measurements

Tian et. al., *submitted to Phys. Med. Biol.* (2014)



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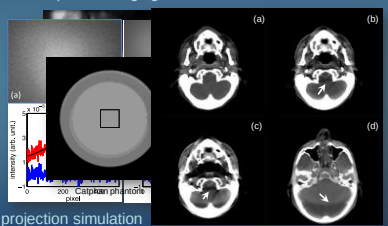
gCTD/MCDRR

- Realistic simulations of CBCT imaging process
  - Facilitate CBCT related projects
  - Evaluate patient-specific imaging dose



- Primary
- Scatter
- Noise
- CBCT

- Time:
  - 1 min per projection simulation
  - 20sec for dose calculations

Jia, et. al., *PMB*, **57**, 577 (2012)
Jia, et. al., *Med. Phys.*, **39**, 7368 (2012)

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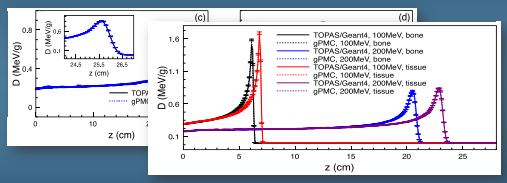
gPMC

- In collaboration with MGH group
- Combines the physics from literatures



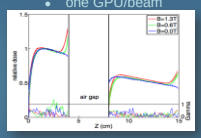
- Time: 6~22 sec of computation time
- In the process of clinical evaluations

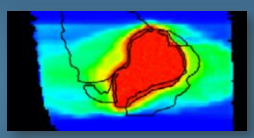
Jia, et. al., *Phys. Med. Biol.*, **57**, 7783 (2012)
Jia et. al., *AAPM 2013*
Giantsoudi, et. al., AAPM 2014

Other GPU packages

- GPUMCD
  - ~2 min dose calc + optimization,
  - one GPU/beam

Hissoiny, et. al., *Phys. Med. Biol.*, **56**, 5119 (2011)
Bol et. al., *Phys. Med. Biol.*, **57**, 1375 (2012)





- GMC:
  - Geant4 implementation
  - 349 sec on GTX 580

Jahnke, et. al., *Phys. Med. Biol.*, **57**, 1217 (2012)

- ARCHER$_{RT}$
  - 60~80 sec on Tesla M2090

Su, et. al., *Med. Phys.* **41,** 071709 (2014)

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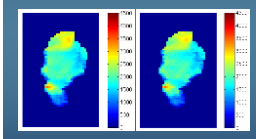
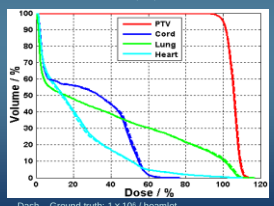
Treatment (re)-planning

- Pencil beam dose calculations using MC
- Adaptively sample particles based on optimized MU
  - Acceleration 4X (in addition to acceleration of MC by GPU)



Optimized fluence map with 1×10^6 / beamlet and 1×10^4 / beamlet/iteration

TH-E-BRE-8, Li, et. al.



Dash – Ground truth: 1×10^6 / beamlet
Solid - 5×10^3 / beamlet with 9 iteration

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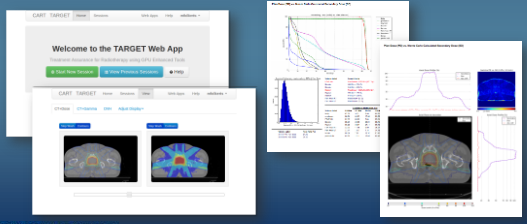
Pre-treatment

- A web-based service for treatment plan verification
  - User upload a plan
  - gDPM runs on a GPU server
  - Plan dose is verified and a report is generated



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In/post-treatment

- Real-time simulation of photon dose delivery using (simulated) online machine log

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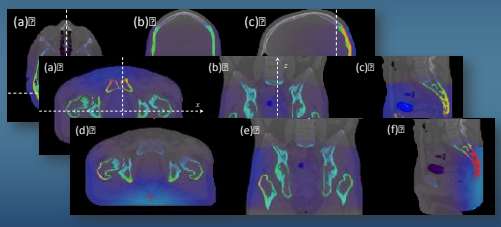
CBCT dose calculations

- Accurate evaluation of patient-specific dose in CT scans

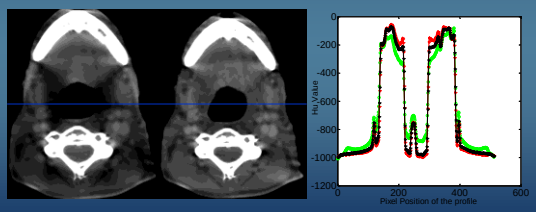


Montanari, et. al., *PMB*. **59**, 1239 (2014)

CBCT scatter

- Estimate scatter signals using MC
- 2 FDK reconstruction + 1 MC in 30 sec

Xu, et. al., submitted to *PMB*. (2014)



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Conclusions

- GPU is a great tool for MC simulations
- Fast, or almost near real-time dose calculation is possible
- Enable new and novel applications

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