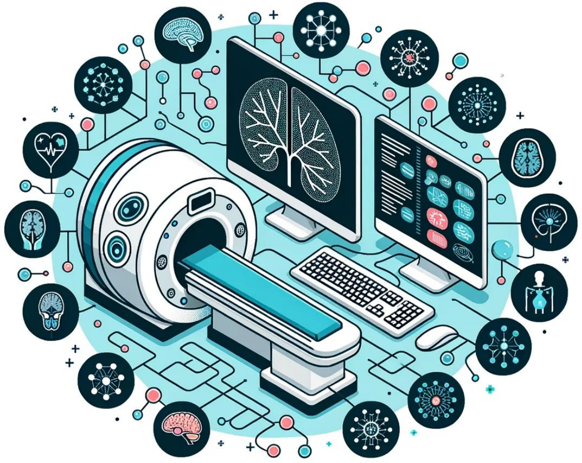
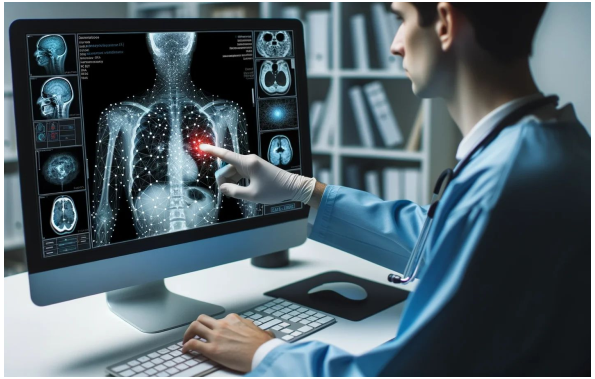
Applied Deep Learning and Generative Models in Healthcare



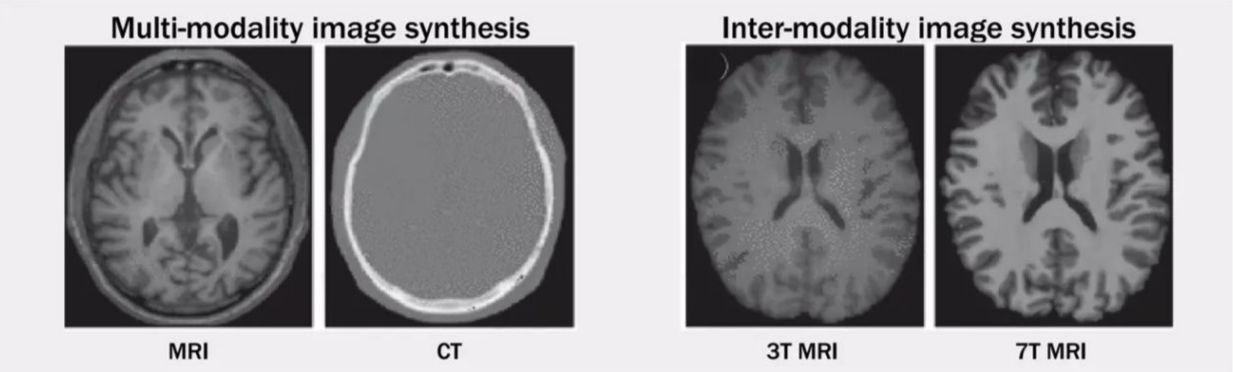


Session 5: Medical Image Synthesis
Date: Feb 15 2025

Instructor: Mahmoud E. Khani, Ph.D.

Medical image synthesis

- **An approach to modeling a mapping from given images to unknown images**
- **Necessity**
  - Potential risk of radiation exposure for multiple acquisition of medical images (ec. CT, PET)
  - Not always accessible modalities for every patient
  - Alignment issue on the analysis of multi-images

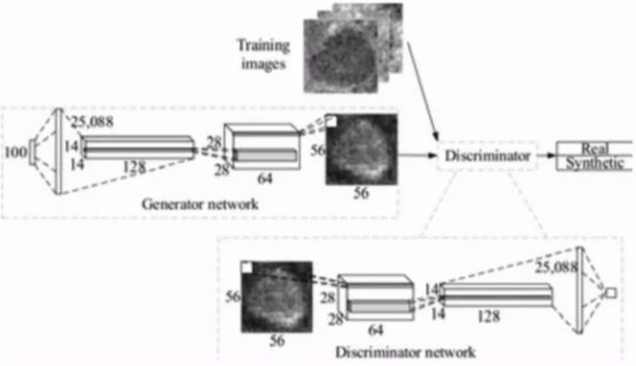


Nie, Dong, et al. "Medical image synthesis with deep convolutional adversarial networks." *IEEE Transactions on Biomedical Engineering*

Deep learning approaches for image synthesis

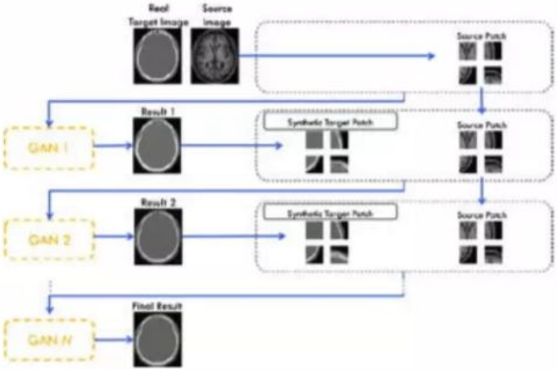
- Image generation by solving the min-max problem with generator and discriminator
- Useful for the dataset that does not have ground-truth images

DCGAN model



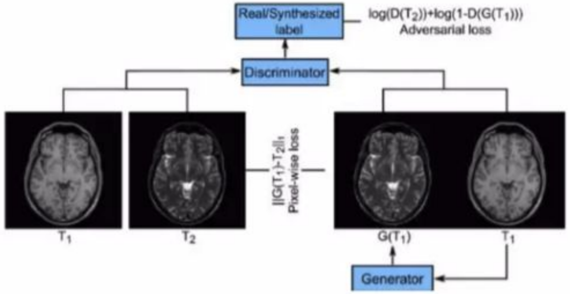
Zhang, Qianqian, et al. ICHI, 2018

Auto-context model with GAN



Nie, Dong, et al. *IEEE* TBE, 2018

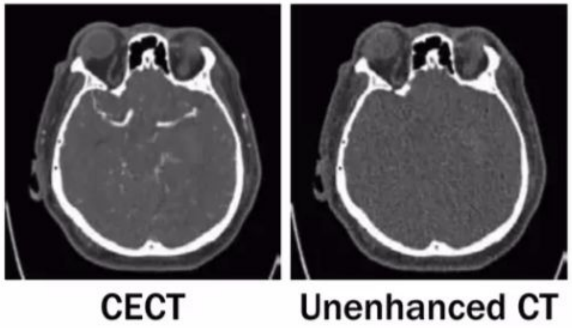
Conditional GAN model



Dar, Salman UH, et al. IEEE TMI, 2019

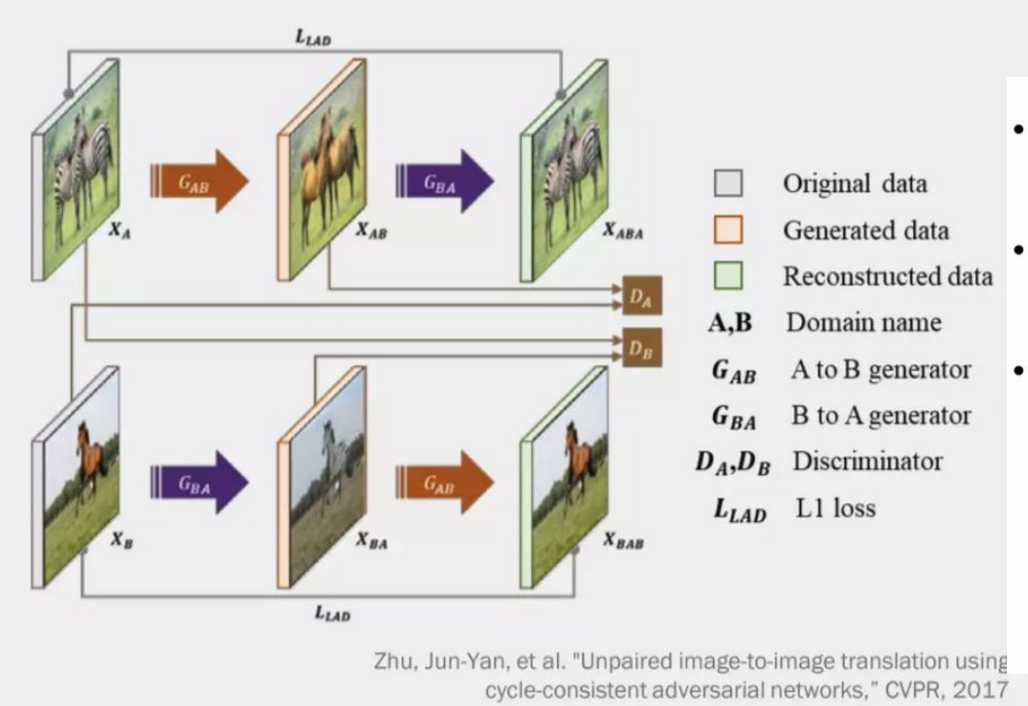
CT image synthesis from CECT

- **CECT and unenhanced CT**
  - CECT: highlight specific tissues or parts of body by contrast agent
  - Useful for diagnosis by extracting certain organ (ex. bone)
- **Challenge**
  - Not aligned CT & CTEC: not have ground-truth images
  - Only have to change the enhanced blood vessels
  - Do not generate or remove certain organs/tissues



Motivation: CycleGAN

- One-to-one mapping using cycling constraint



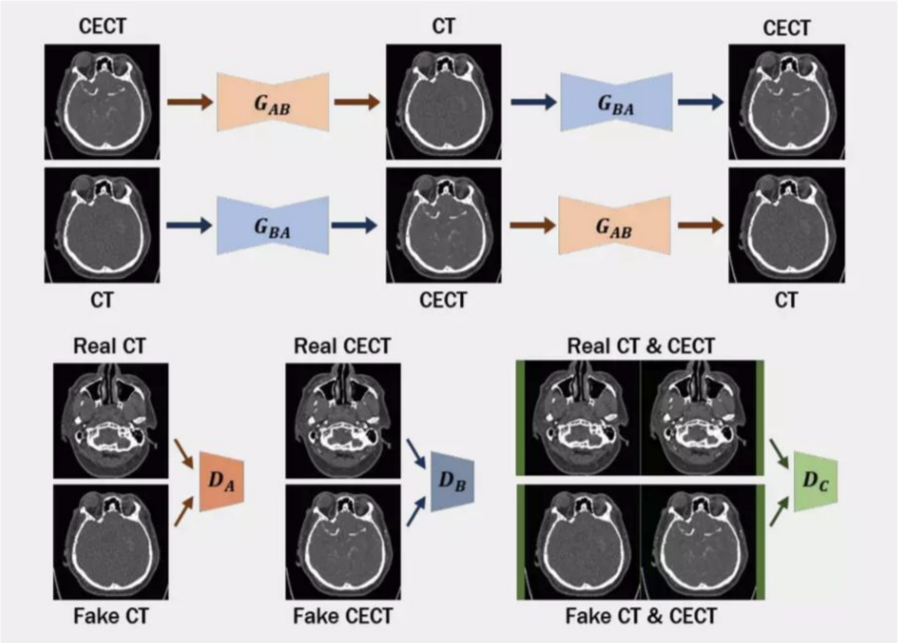
- **Two Generators**
  Generate the unknown image from source image
- **Two Discriminators**
  Distinguish between real and fake images
- **Loss function**

$$\min_{G_{AB},G_{BA}} \max_{D_A,D_B} L(G_{AB},G_{BA},D_A,D_B)$$

$$L(G_{AB},G_{BA},D_A,D_B)$$
$$= L_{GAN}(G_{AB},D_A) + L_{GAN}(G_{BA},D_B)$$
$$+ \lambda_1 L_{cyclic}(G_{AB},G_{BA}) + \lambda_2 L_{identity}(G_{AB},G_{BA})$$

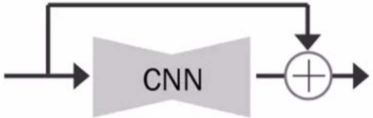
Overall framework

- **Improved cycleGAN with residual learning**



- **Residual learning for generators**

  Prevent loss of medical information



- **Two Generators**

  G_{AB} : CECT → CT (generate synthetic CT)

  G_{BA} : CT → CECT (generate synthetic CECT)

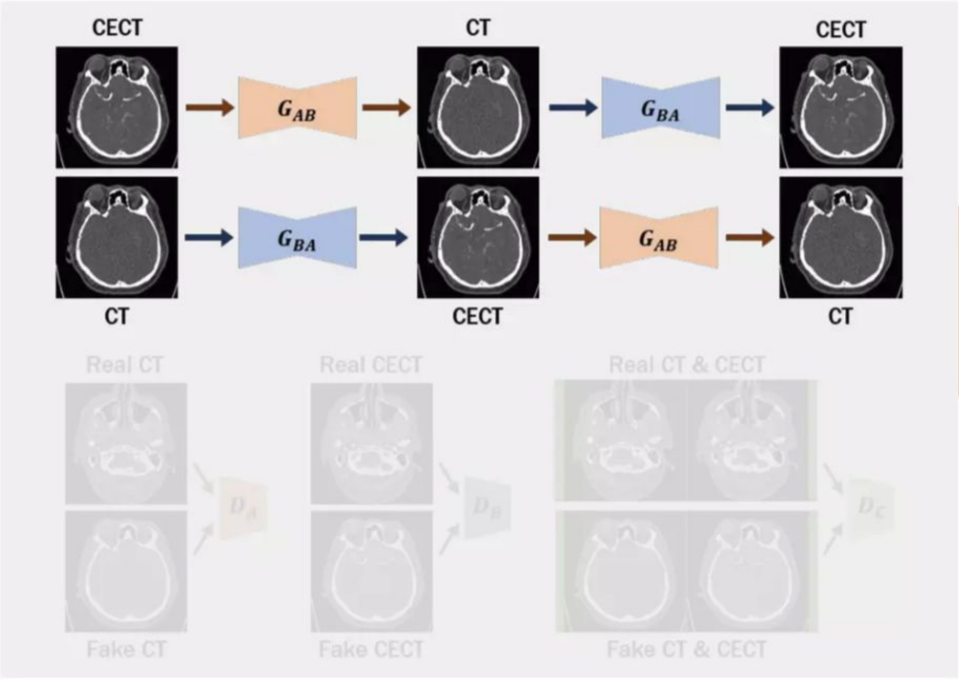
- **Three Discriminators**

  D_A : Distinguish real and fake CT

  D_B : Distinguish real and fake CECT

  D_C : Distinguish real and fake pair of CT & CECT

Overall framework



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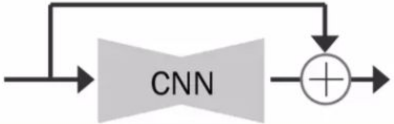

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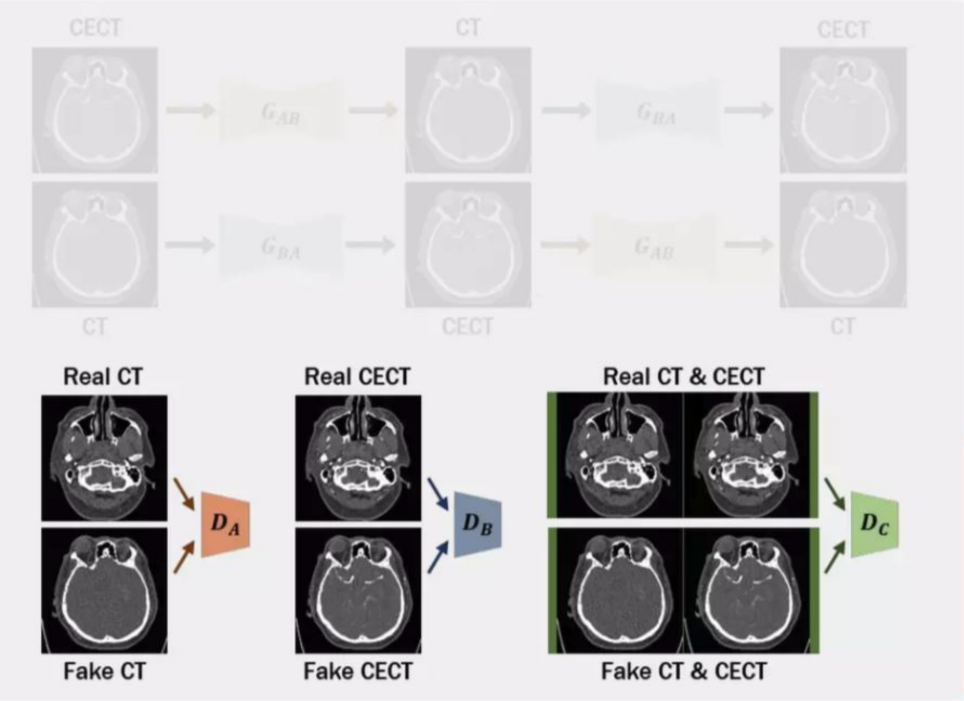

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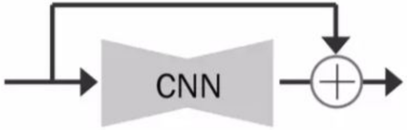

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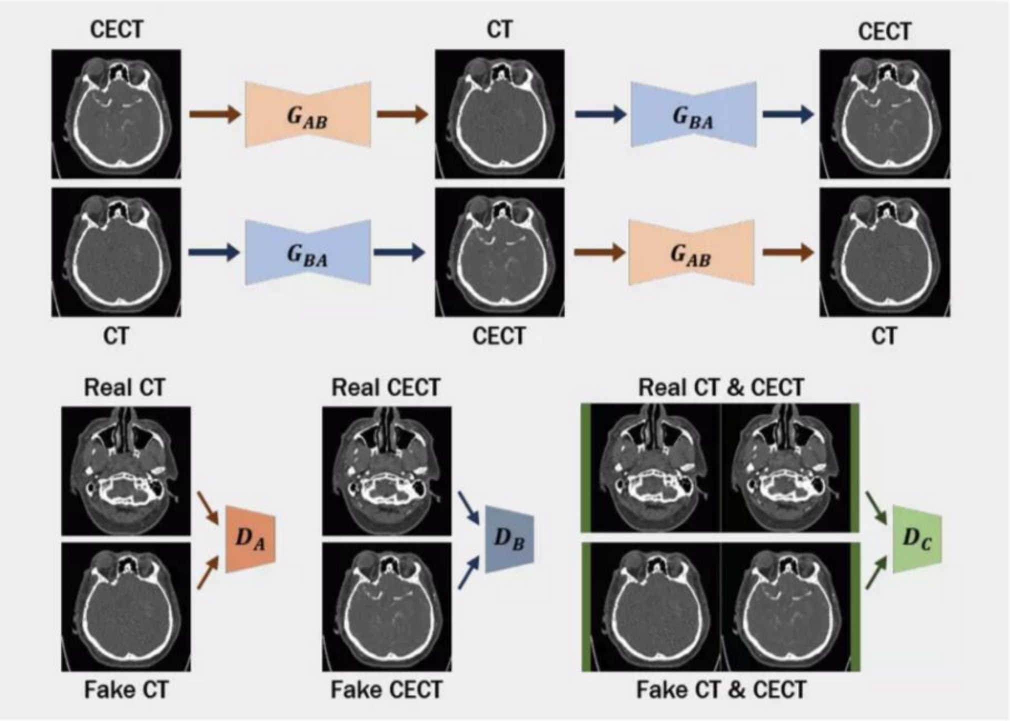
Loss function

- **Training networks by solving the optimization problem**

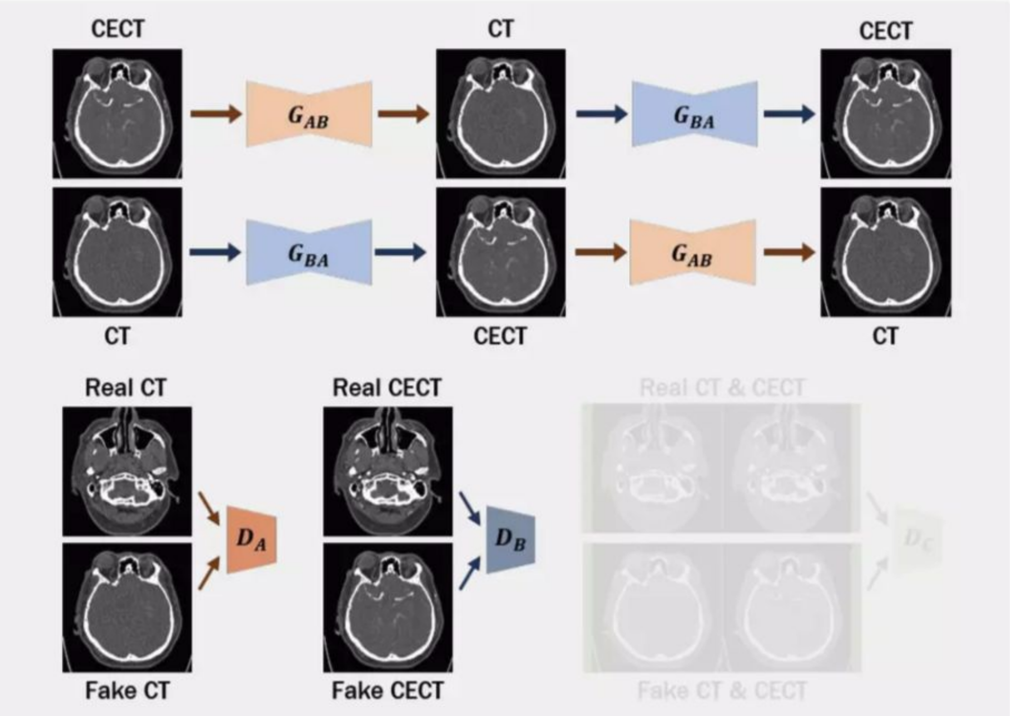


$$\min_{G_{AB},G_{BA}} \max_{D_A,D_B,D_C} L(G_{AB},G_{BA},D_A,D_B,D_C)$$

$$\begin{aligned}
&L(G_{AB},G_{BA},D_A,D_B,D_C)\\
&\quad = L_{GAN}(G_{AB},D_A) + L_{GAN}(G_{BA},D_B) + L_{GAN'}(G_{AB},G_{BA},D_C)\\
&\qquad + \lambda_1 L_{cyclic}(G_{AB},G_{BA}) + \lambda_2 L_{identity}(G_{AB},G_{BA})
\end{aligned}$$

Loss function

- **Training networks by solving the optimization problem**



$$\min_{G_{AB},G_{BA}} \max_{D_A,D_B,D_C} L(G_{AB}, G_{BA}, D_A, D_B, D_C)$$

$$\begin{aligned} L(G_{AB}, G_{BA}, D_A, D_B, D_C) \\ = L_{GAN}(G_{AB}, D_A) + L_{GAN}(G_{BA}, D_B) + L_{GAN'}(G_{AB}, G_{BA}, D_C) \\ + \lambda_1 L_{cyclic}(G_{AB}, G_{BA}) + \lambda_2 L_{identity}(G_{AB}, G_{BA}) \end{aligned}$$

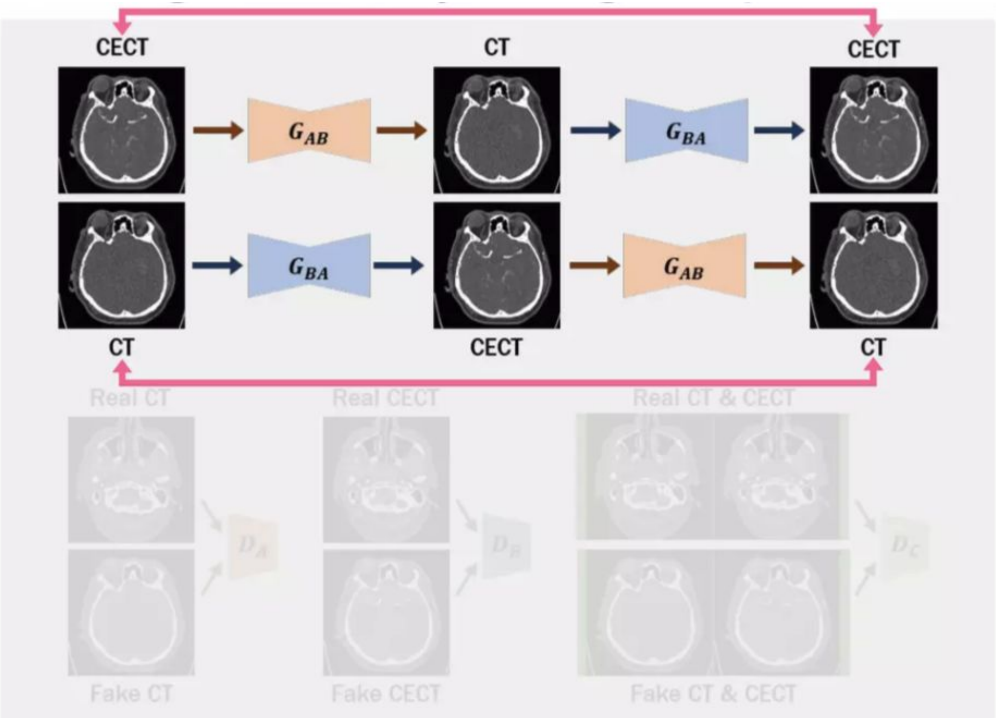
- Adversarial loss, $\boldsymbol{L_{GAN}(G_{AB}, D_A)}$
  - Produce realistic images
  - Apply to input x

$$\min_{G_{AB}} \mathbb{E}_{x_A \sim P_A}[(D_A(G_{AB}(x_A)) - 1)^2]$$

$$\min_{D_A} \frac{1}{2}\mathbb{E}_{x_B \sim P_B}[(D_A(x_B) - 1)^2] + \frac{1}{2}\mathbb{E}_{x_A \sim P_A}[D_A(G_{AB}(x_A))^2]$$

Loss function

- **Training networks by solving the optimization problem**



$$\min_{G_{AB},G_{BA}} \max_{D_A,D_B,D_C} L(G_{AB}, G_{BA}, D_A, D_B, D_C)$$

$$\begin{aligned} &L(G_{AB}, G_{BA}, D_A, D_B, D_C) \\ &\quad = L_{GAN}(G_{AB}, D_A) + L_{GAN}(G_{BA}, D_B) + L_{GAN'}(G_{AB}, G_{BA}, D_C) \\ &\quad\quad + \lambda_1 L_{cyclic}(G_{AB}, G_{BA}) + \lambda_2 L_{identity}(G_{AB}, G_{BA}) \end{aligned}$$

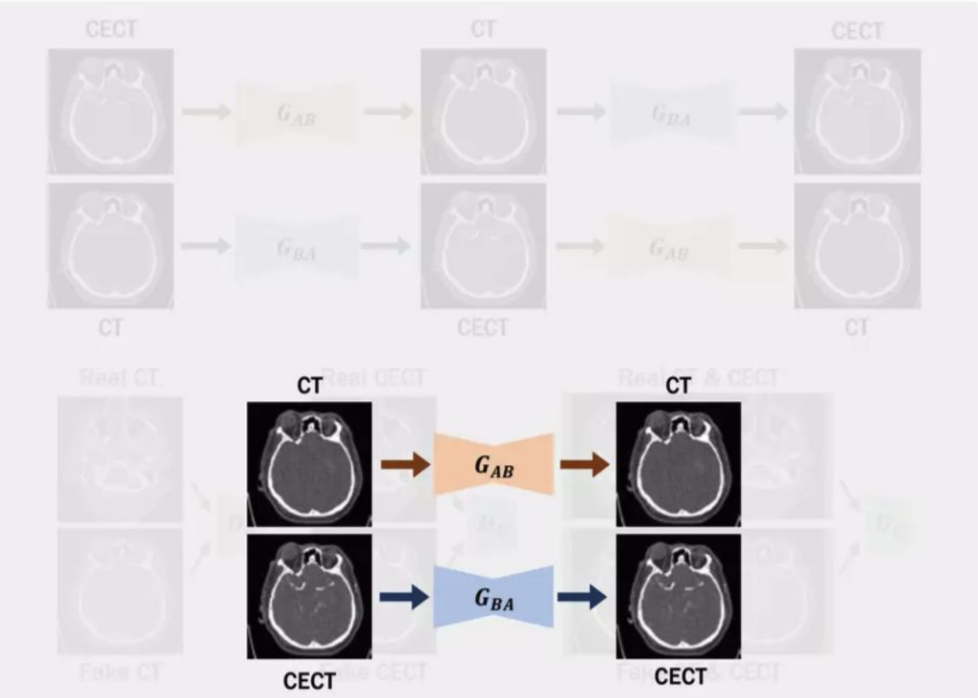
- **Cyclic loss,** $L_{cyclic}(G_{AB}, G_{BA})$

  Guarantee one-to-one mapping of CT & CECT

$$\begin{aligned} &\mathbb{E}_{x_A \sim P_A}\left[\left\| G_{BA}(G_{AB}(x_A)) - x_A \right\|_1\right] \\ &+\mathbb{E}_{x_B \sim P_B}\left[\left\| G_{AB}(G_{BA}(x_B)) - x_B \right\|_1\right] \end{aligned}$$

Loss function

- **Training networks by solving the optimization problem**



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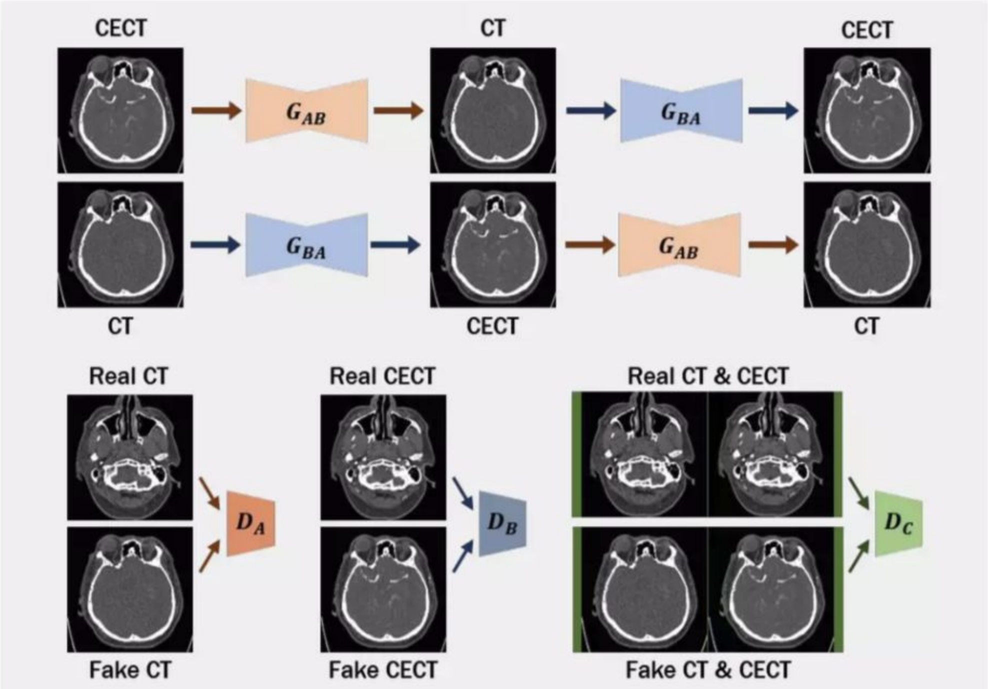
- Identity loss, $L_{identity}(G_{AB}, G_{BA})$

  Preserve medical information between CT & CECT

$$\mathbb{E}_{x_A \sim P_A}[\|G_{BA}(x_A) - x_A\|_1] + \mathbb{E}_{x_B \sim P_B}[\|G_{AB}(x_B) - x_B\|_1]$$

Loss function

- **Training networks by solving the optimization problem**



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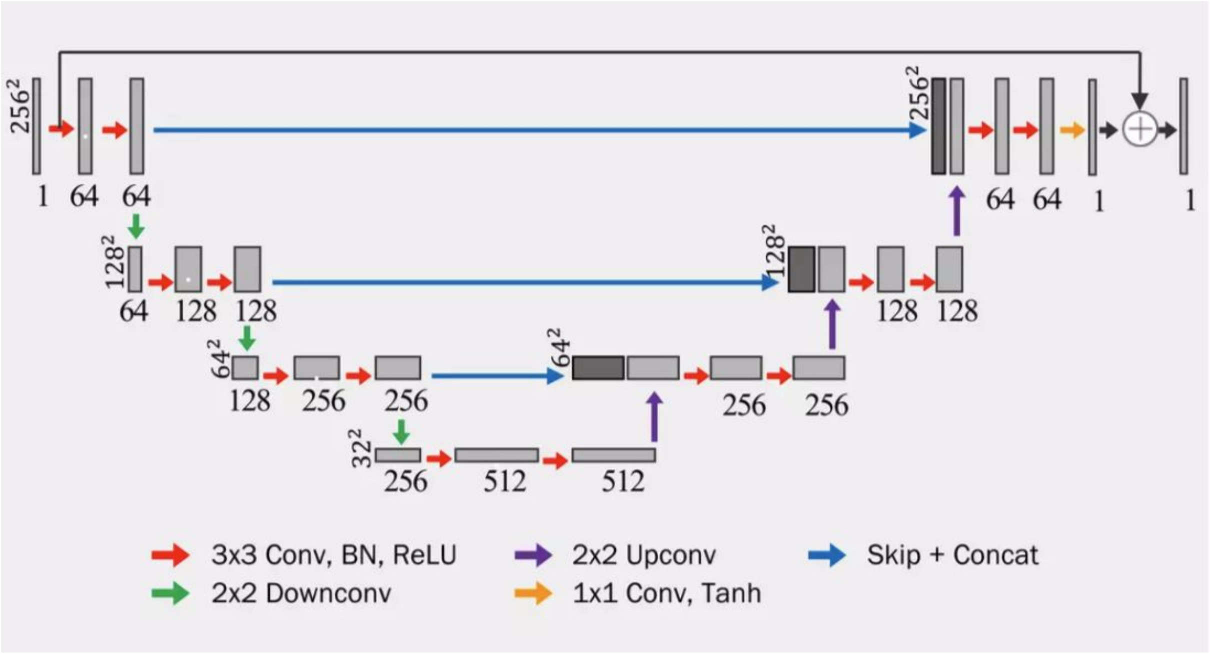
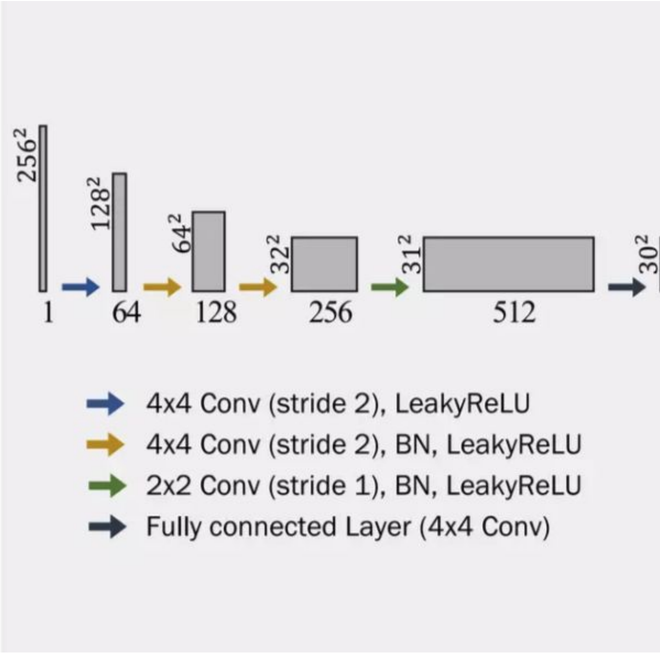
- Minimize our designed loss function (adversarial loss + cyclic loss + identity loss)

Network architecture

- Generator (UNet)
- Discriminator





Experiments (Next session)

- **Dataset**
  - Head CT & CECT scans
    - 10 paris of CT & CTECT scans
    - 8 scans for training / 2 scans for test