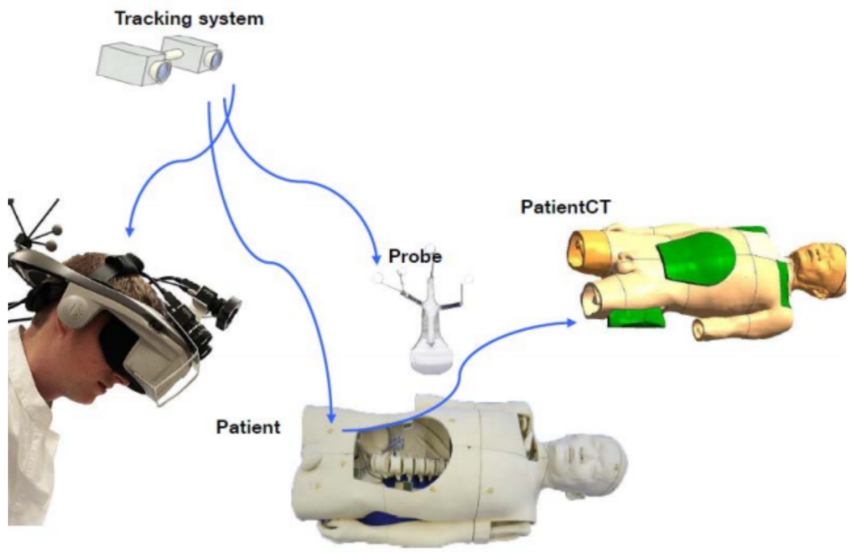
Medical Augmented Reality



- **Tracking System**
  - optical, marker based
    - most popular tracking method
    - estimate pose of a well-known pattern that is optimized for tracking
    - simple
    - markers problematic for medical AR
  - optical, feature based
    - estimate pose of a pattern
    - doesn’t require additional markers
    - accuracy and precision depend on object
    - endoscopes / bronchoscopes
  - optical, infrared based 紅外線
    - optical camera with infrared filter
    - marker based tracking with infrared camera
    - passive → reflective spherical markers
    - active → infrared LEDs
    - inside-out
      - **moving** tracking system → attach to display
      - less problem of line of sight
      - higher angular accuracy
    - outside-in
      - **fixed** tracking system
      - multiple cameras → large tracking volume, stable, accurate & precise

- Depth-camera based
    - structured light (kinect)
    - laser rangefinder
    - time of flight
    - stereo reconstruction
    - coded aperture
    - plenoptic lense
    - lightfield camera
    - **skeleton tracking**
      → less precise, Only some relevance for medical education
    - **Featured-based object tracking**
      → Similar to normal feature-based tracking
      → Uses RGB-D instead of RGB

- **Optical Tracking**

Good	**Bad**
1. High accuracy 2. Big tracking volume (multiple cameras) 3. Marker-based: High precision	1. Line of sight problem 2. Markers must be attached

- **Electromagnetic Tracking (**new for medical application**)**
  - magnetic field generated by field generator
  - sensor detects its position within the magnetic field
  - works similar to a compass

Good	**Bad**
1. No line of sight problem 2. Reasonable accuracy and precision	1. Required cables or power supply 2. Problems with ferromagnetic material 3. Small tracking volume

- **Mechanical Tracking**
  - **Track the pose of the end-effector of a robot arm**
  - Flexible shape tracking

Good	**Bad**
High precision & accuracy	Requires mechanical link

- **Other types**
  - **Inertial** → small&light, need cable, initialization problem
  - **US** → time of flight principle, not at accurate as optical/magnetic
  - **Hybrid tracking** → combination of tracking systems (**magnetic&optical**), complex but reduce problem

Registration → pre-operative / intra-operative images

- **Rigid registration**
  - markers (visible in both tracking & image)
  - pointer (positioned on defined points)
  - does not consider changes between image & current situation
- **Deformable registration**
  - still some problems and solution depends on application

Calibration

- camera :
  - intrinsic parameters (focal length, distortion)
  - extrinsic parameters (transformation between tracked point & camera center)
  - standard camera calibration
- tools :
  - tool tip calibration
  - tool axis calibration
- imaging device intrinsic parameters
  - c-arm, US, nuclear probe

Display Devices

- Head-mounted display (HMDs)
  - video see through (**VST**) & optical-see throught (**OST**)
  - **VST**
    - video cameras + monitors (lenses : has a minimum focus distance)
    - **highest quality for real object (lower immersion)**
  - **OST**
    - semi-transparent display (user sees reality plus overlay
    - can only **brighten the real image & no occlusion of real object by virtual objects**

	Video See-through (VST)	**Optical See-through (OST)**
Good	One-time calibration Image more consistent Virtual objects can occlude real objects Better synchronization	Lightweight Small Good quality of real scene
Bad	Heavy Big Limited field of view Limited resolution Limited dynamic range Black out due to errors	Re-calibration Possible misalignment Virtual objects cannot occlude real object

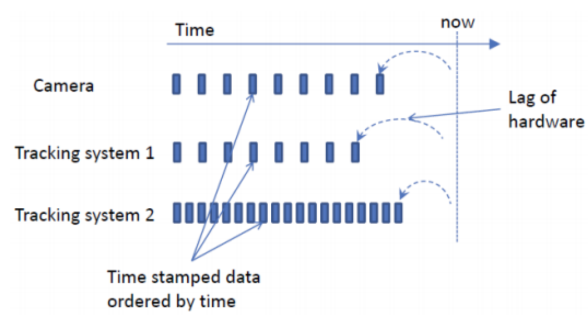
Medical Visualization

- Normal computer graphic → mainly surface rendering
- Medical visualization
    - surface rendering
      → fast, easy, only small portion of data is shown, requires prior surface extraction
    - Direct Volume Rendering (DVR)
      → no prior extraction of surface, Various possibilities for classification, shading, direct online update
    - **Transfer Function**
        - maps image intensities (Hounsfield values) to color and transparency
    - How to display a volume in AR?
        - simple overlay lead to bad depth perception
        - solution : virtual window
    - **Advanced focus & context visualization**
        - show virtual object → through a focus window
        - show skin → where surface has a high curvature曲線

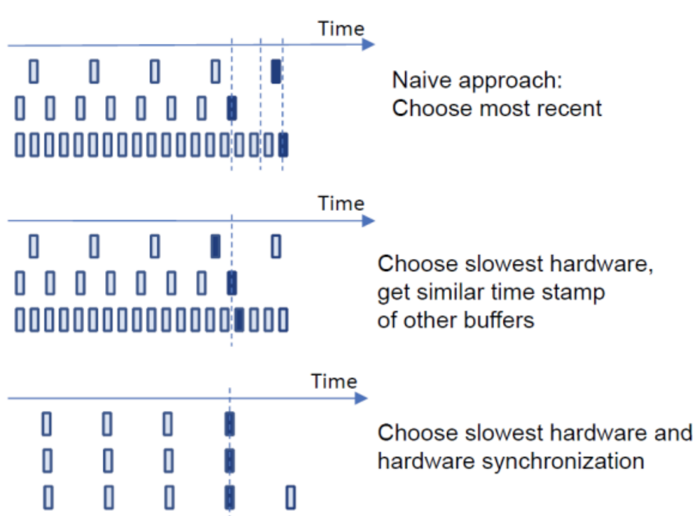
Synchronization

- Problem:
    - different data sources : tracking, video cameras, imaging device
    - different update rates & lag

  e.g. **high delay for tracking low delay for video image → virtual object will lag behind**



- Solution : Add delay to slower data source
- Stages :



User Interface

- Increasing for UI
    - computer assisted surgery
    - new visualization methods
    - intra-operative 3D imaging
- Possible solution → AR
    - Interact with 3D data without requiring mouse & jeyboard
    - some sort of input device is still required

Point-Based Registration (PCA & ICP)

- Registration Problem
  - Given → Two shapes **P** & **Q** which partially overlap
  - Goal → Using only rigid transformation, Register **Q** against **P**
    → minimizing the Square distance between!!!
- Approaches
  - Iterative algorithm
  - Voting methods
  - Geometric description

ICP

- **Iterative Minimization Algorithm**
  - Build a set of corresponding points
  - Align corresponding points
  - Iterate
- Properties
  - Dense corresponding sets
  - **Converges if starting positions are "close"**
- Hard ?
  - unknown areas of overlap
  - have to solve the correspondence problem
- Easy?
  - Rigid transform is specified by small number of points
  - Prominent features are easy to identify

- **Correspondence 3D Point Sets - Problems**
  - Given : 2 corresponding point sets in 3D
  - Task : Find the rigid motion H between the point sets
    → H has 6DOF transformation → known as Procrustes Problem
  - Demean the point sets
  - Compute rotation with SVD of correlation matrix
  - Compute translation

- **Summary**
  - **Good if correspondences are known!**
  - If no corresponding points → combine PCA-ICP
  - **PCA** → use center of masses & principal components of point clouds for initial estimate of Rotation, translation
  - **ICP** → iterative solution to registration problem form initial estimate

PCA-ICP

- **Non-Corresponding 3D Point Sets**
  - First demean point sets
  - **PCA** → calculate the SVD of the covariance matrices
  - Rotation R = RyRx
  - Translation
  - Then **iterative Closest Point (ICP)**
    - Input : 2 spatial entities (point sets, surfaces, curves) E1, E2
    - Output : Transformation R, t, such that E2 = RE1 + t
    - Init : ^E1 := E1
  - **ICP**
    - **Step1 -** Determine the closest points in E1 → Match M_E1,E2
    - **Step2 -** Update the Matching M_E1,E2 using a statistical analysis to get rid of outliers → Match ^M_E1,E2
    - **Step3 -** Assume the points in ^M_E1,E2, correspond & estimate the motion R, t using some linear analytical method
    - **Step4 -** Apply the motion R,t to all points in E1, and repeat until convergence
  - When to converge?
    - As in many iterative optimization schemes, the difference in cost function evaluations is deciding on **termination**
      - t_{old} and t_{new} are translations from previous and current iteration.
      - α_{old} and α_{new} are axes of rotation from previous and current iteration.
      - If $((t_{old} - t_{new}) < \epsilon \ \&\& \ \sqrt{(\alpha_{old} - \alpha_{new})^T(\alpha_{old} - \alpha_{new})} < \epsilon)$ terminate.

Medical Simulation

Why medical simulation - based learning?

- Standardized environment for objective performance assessment
- Possibility to repeatedly practice procedures
- Gaining experience from conducting difficult procedures

What is Vision & Mission of research group? **“simulation in medical education!”**

- **Vision** → Establishing a simulated OR theater for the evaluation of novel medical computer and human/device interfaces
- **Mission** → Validation of medical simulation environment or multidisciplinary team assessment and training

Traditional Training	Proficiency-based progression
1. Simple explanation 2. Lecture 3. real Patient, Mentoring	1. Simple explanation 2. Lecture 3. Formative assessed explanation (online) 4. Emulation models 5. VR Procedure simulation → **Full Environment Simulation** 6. real Patient, mentoring

Clinical Practice → Simulation

	Simulation scenario	Limitations
Patient actor **VR endoscopy simulator**	Patient actor instructed to voice discomfort	No use of medical imaging technology
Mannequin simulator 模特機器 **Synthetic vein model**人造血管	1. Bleeding is started at a standardized point (artificial blood) 2. Crisis simulated with mannequin	1. Medical expert observer assesses performance and stop bleeding 2. Surgical workspace is not spatially correctly aligned with simulated patient

<u>Fundamentals of Surgical Simulation</u>

1. Controlled deliberate practice

→ capacity for the trainer to control the introduction of an adverse event to the training scenario

2. Critical event

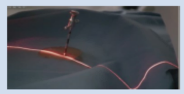
→ adverse events should influence anatomical & physiological model of the simulated patient

3. Human sensory channel

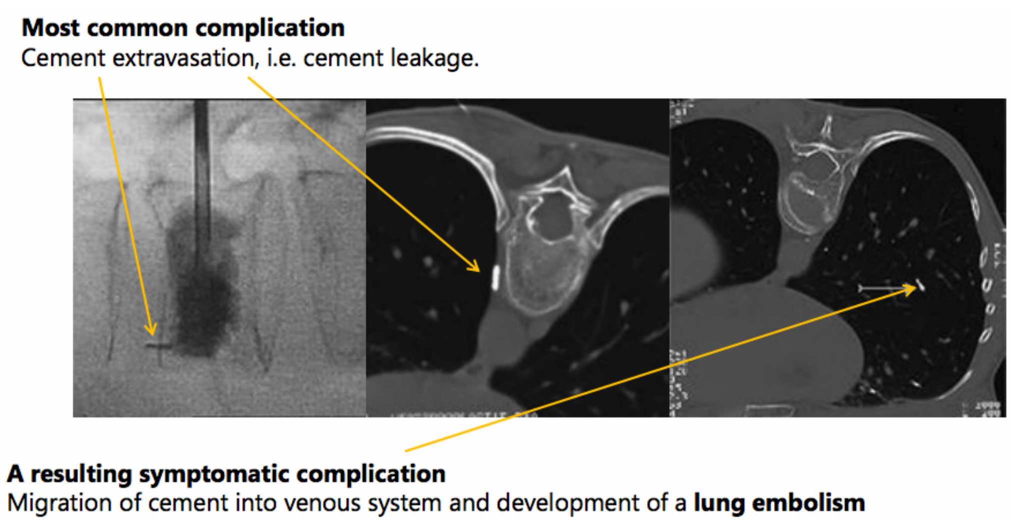
→ Tactile, auditory and visual channels in real-time should be addressed

Minimal-invasive procedure： Vertebroplasty 脊椎成形術

- <u>Procedure workflow</u>

Steps	Definition of entry point	Navigation of the trocar into the vertebra	Application of cement
Tasks	• Small incision made with scalpel 	• Positioning of trocar 	• Cement injection 
Instruments	Scalpel 	Trocar 	Syringe 
Learning Objectives	Choice of entry point	Access path	Cement application

- <u>Adverse Event</u>



- <u>Importance of situational awareness</u>
  - **Failure to recognize cement leakage**
    - lack of monitoring cement flow in caudal.cranial direction during (CT) guidance
  - **Situational awareness**
    - An anaesthesiologist aware of the procedure related risks can interpret clinical signs of an complication → pulmonary肺
  - **Communication**

        - Interpreting the situation may therefore involve communication between surgeon and anesthesiologist

Haptic Simulation 觸覺模擬
- Devic : Novint Falcon → Translation-only 3DoF
- **Volume-based** haptic primitive approach
    - Trocar progression
    - Deviation from trajectory
- **Proxy-based** surface haptic rendering method
    - Bone model with high simulated stiffness
    - Simulation of bone penetration by dropping resistance of applied foce exceeds threshold

Simulated CT Visualisation
- Trocar
- Cement
- Cement leakage (for crisis simulation)

Simulated auditory elements
- CT scanner
- Patient monitor

Standardized "simulated " anesthesiologist
- Actor instructed to communicate patient status to surgeon