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DoF-based Classification of Augmented Reality Applications

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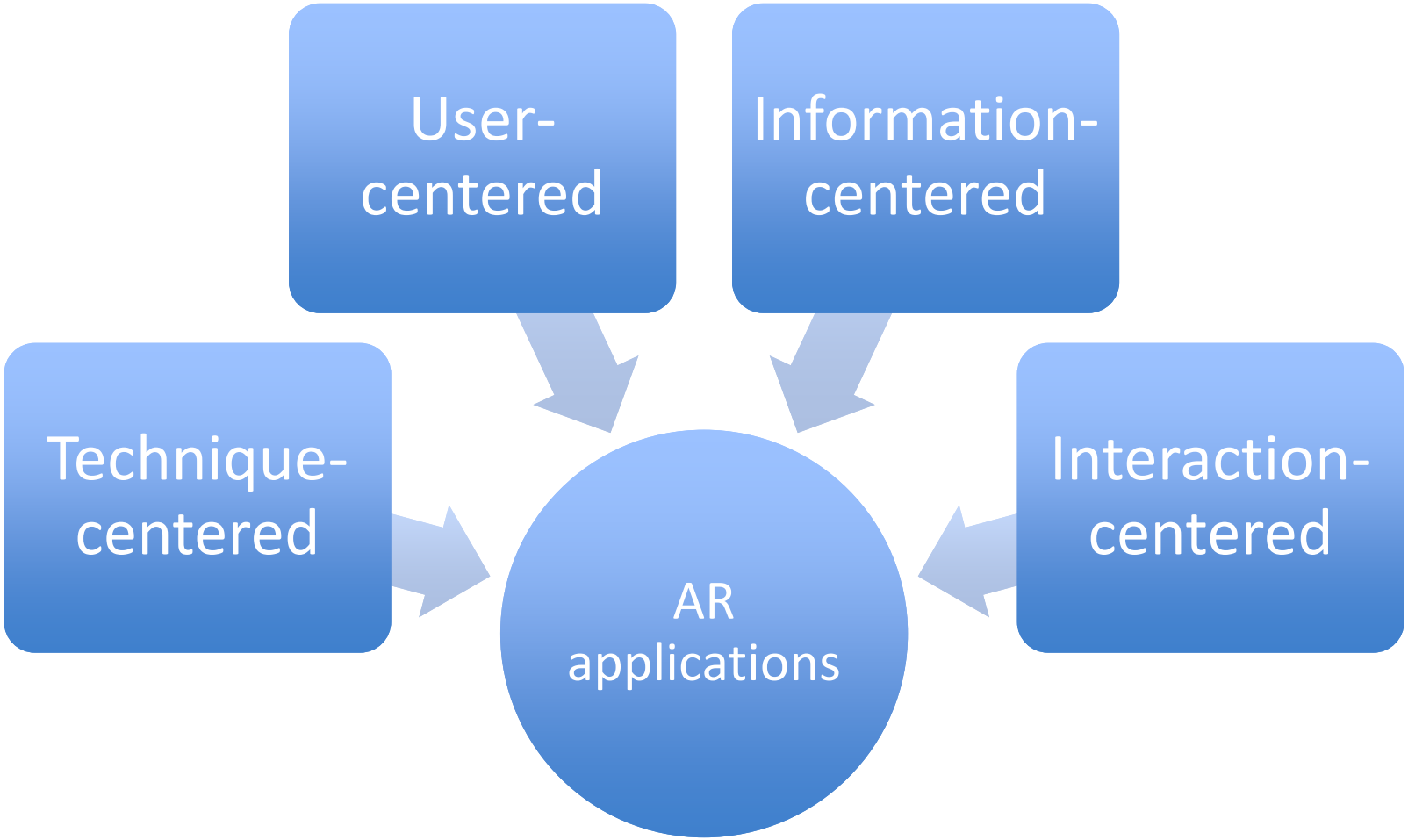
Outline

- Existing taxonomies:
  - Characteristics
  - Limitations
- Proposal
- Classification examples
- Possible extensions
- Conclusions

Existing Taxonomies



Existing taxonomies: characteristics

Technique-centered	User-centered	Information-centered	Interaction-centered
• Type/Centricity of display used • Congruency of mapping • [*Milgram et al.*]	• Human perception of the AR stimulus • [*Lindeman & Noma*]	• Location-based information • [*Suomela & Lehikoinen*]	• Target of the augmentation • [*Mackay*]
	• Functionalities of AR applications • [*Hugues et al.*]		• Tasks to be performed • [*Dubois et al.*]
• Technical criteria of the apps • [*Braz & Pereira*]	• "Collaborativeness" • [*Wang & Dunston*]	• Presentation space of the information • [*Tönnis & Plecher*]	• Ubiquitous Computing • [*Newman et al.*]

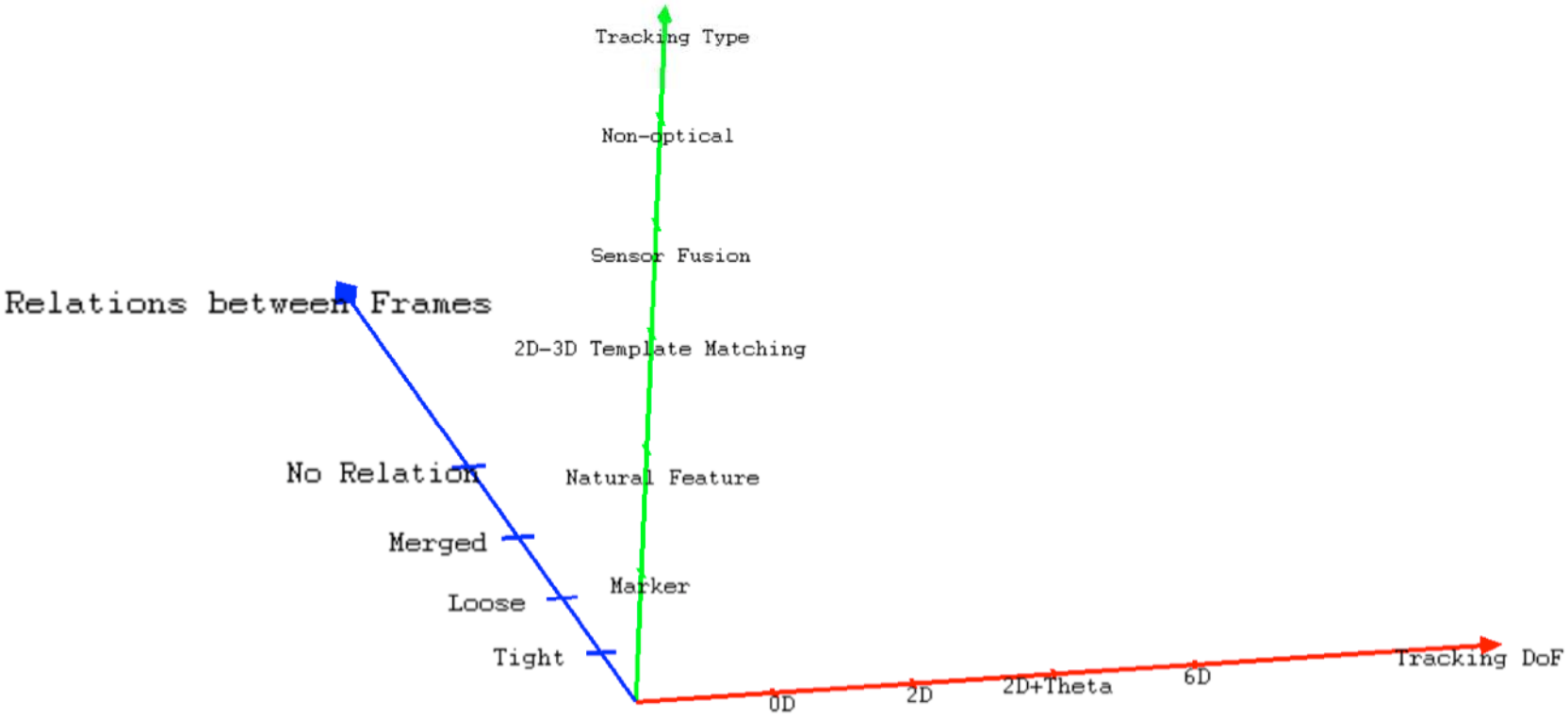
Existing taxonomies: limitations

Technique-centered	User-centered	Information-centered	Interaction-centered
• No mobile AR • No multi-modality • Not very discriminative • "Presence" in AR/MR • [*Milgram et al.*]	• Not discriminative enough • Merging different modalities together? • [*Lindeman & Noma*]	• Only for location-based apps • No multi-modality • [*Suomela & Lehikoinen*]	• Not discriminative • No multi-modality • [*Mackay*]
	• Limited to visual apps • Axes not fully convincing • [*Hugues et al.*]		• Not a real classification of AR apps • [*Dubois et al.*]
• Long list of features instead of discriminative criteria • Not maintained anymore • [*Braz & Pereira*]	• Only collaborative AR • Limited to construction-based apps • [*Wang&Dunston*]	• No multi-modality • Some vague criteria • [*Tönnis & Plecher*]	• Limited to 2 axes (VR continuum and Weiser continuum) • [*Newman et al.*]

Proposal

- 4 “axes” taxonomy:
  1. Tracking-DoF required by the app
  2. Relations between frames of references
     - User, sensor(s), display system(s), real world
  3. Type of tracking used by the application
     - Marker-based, Natural-feature, Template Matching, Optical + Sensor-fusion, Non-optical
  4. Other rendering modalities (optional)
     - Audio, haptic, gustatory, olfactory

Proposal without Optional Non-Visual Rendering Modality



Tracking DoF

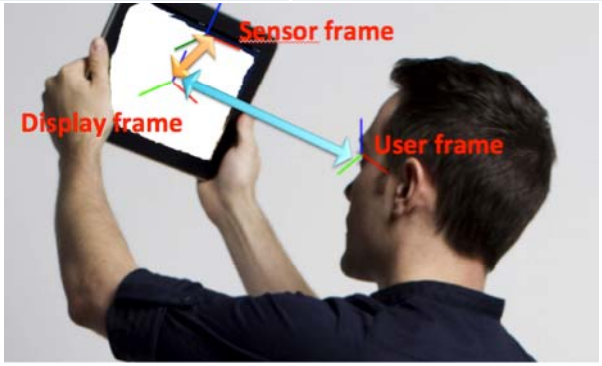
- 0D: detect a marker and display information not related to the position or orientation of the marker (e.g. QR code).
  - Precision: N.A.
  - Update rate: N.A.
- 2D: location-based services (e.g. Google Maps).
  - Precision: ≈ decametric
  - Update rate: ≈ 1Hz.
- 2D+θ: location-based + 1D-orientation (e.g. locating nearby restaurants, etc.)
  - Precision: ≤ decametric
  - Update rate: ≈ 1-10Hz
- 6D: 3D position + 3D orientation (of the marker, device) → "classical" Computer Vision Augmented Reality
  - Precision: ≤ centimetric
  - Update rate: ≈ 10-100Hz

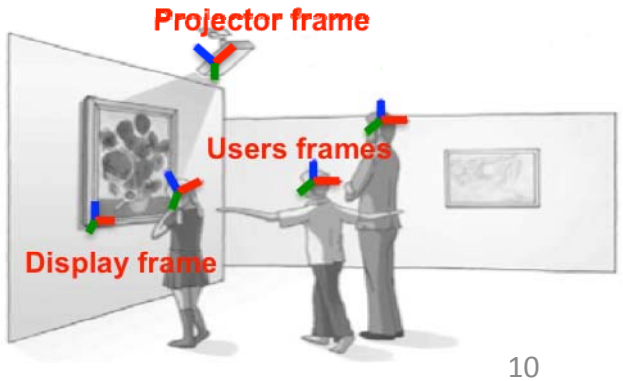
DoF between Frames of Reference

- Relation between the user and the display device
- Display device
  - Optical See-Through (OST):
    - Head-Up Displays (HUDs)
    - See-through Head-Mounted Displays (HMDs)
  - Video See-Through (VST):
    - HMDs
    - Camera-equipped devices. “Magic windows” or “Magic mirrors”
  - Spatially Augmented Reality (SAR)
    - Fixed projector(s) applications
    - User-attached projector(s)
- Relations:
  - Tight
  - Loose
  - Merged
  - No relation

DoF between Frames of Reference

Relation between user and display device frames of reference	Augmented Reality Device
Tight (Rigid) May also include a fixed transformation to some sensors	• OST • HMD-VST • User-projected SAR
Loose	• Handheld VST
Merged	• Location-based Services (LBS) • LBS + Orientation
No relation	• Fixed projector(s) SAR • QR-codes





Tracking Type

- Marker-based (Marker)
- Natural Feature (NF)
- 2D or 3D Template Matching (TM)
- Optical + Sensor Fusion (SF)
  - Camera + Accelerometers/Gyroscopes/etc.
- Non Optical (NO)
  - GPS, compass, etc.

Non-visual Rendering Modalities

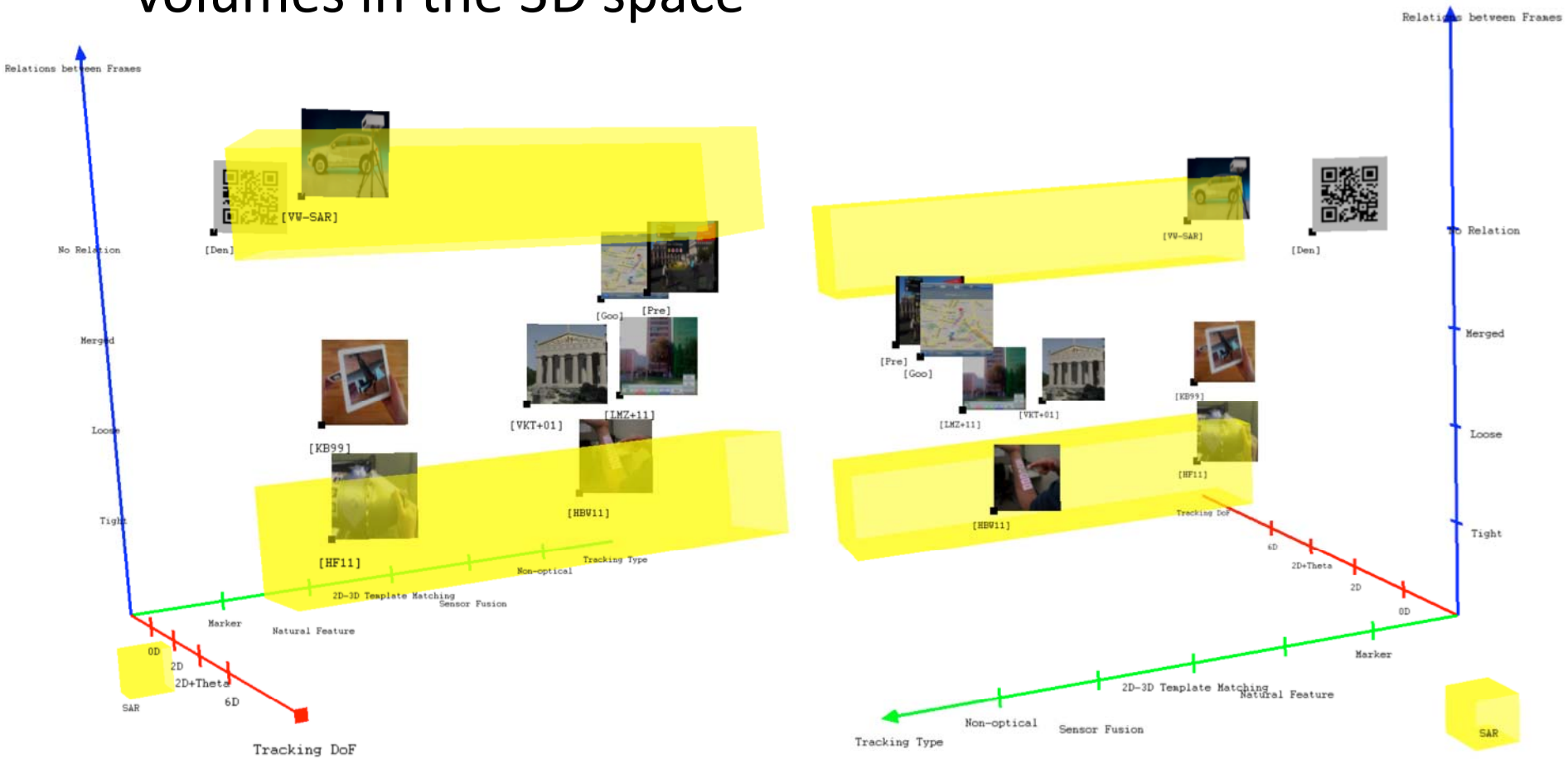
- Visual sense is by far most important for AR
- Idea: extend the DoF approach to other modalities
- Audio:
  - 0D: monoscopic
  - 1D: stereoscopic
  - 2D+θ: binaural
  - 3D: spatialised sound
- Haptic (most popular combination with vision):
  - 0D: simple vibration (e.g. smartphone vibrator)
  - 3D: PHANTOM
- Olfactory:
  - 0D: non-directional stimulus
  - 1D: identified smell direction
- Gustatory:
  - Only touch-based sensors as of today

Classification Examples

Application	Tracking DoF	Relations between Frames	Tracking Type
Archeoguide [40]	6D	Loose	2D TM
InSitu (Outdoors) [18]	6D	Loose	SF
ARMAR [13]	6D	Tight	Marker
VW SAR	6D	No Relation	Marker
Omnitouch [12]	2D+θ	Tight	SF
Metro Paris [30]	2D+θ	Merged	NO
Google Maps [11]	2D	Merged	NO
QR codes [6]	0D	No Relation	Marker
ARToolkit [17]	6D	Loose	Marker

Classification Examples

- Can take into account toolkits → represent them as volumes in the 3D space

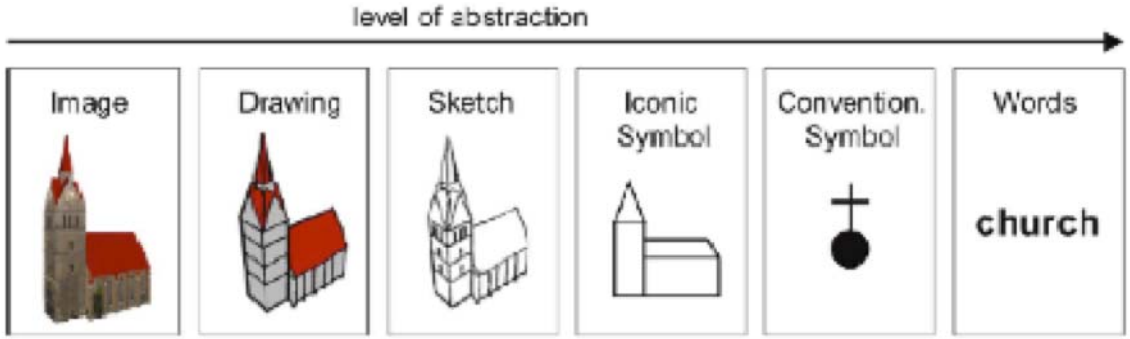


Possible Extensions

- Integration of virtual and real worlds
  - Realistic color/lighting integration of virtual objects
  - Realistic shadowing of the scene by virtual objects
  - Realistic depth integration of virtual objects in the real scene by occlusion management,
  - Interaction between virtual objects and the real world
  - Interaction between the user and virtual objects

Possible Extensions

- How to display information for AR applications
  - Especially for mobile AR
- Level of Abstraction of Virtual Objects?
  - Image
  - Drawing
  - Sketch
  - Iconic symbol
  - Conventional symbol
  - Words
  - Etc.?



Conclusions

- We proposed a taxonomy based on:
  - Dof-based Tracking requirements
  - Dof between frames of references
  - Tracking type
  - Non-visual Rendering Modalities (optional but rarely tackled)
- Provided a small example of AR applications classification based on those criteria
- We believe it overcomes some limitations of previous proposals (of course not all)
  - Mobile AR, Multi-modality, “Discriminative Power” vs. Number of criteria, etc.
- Small number of classification criteria
  - General categories
  - Easy classification of a new application

Future Work

- Work on some extensions:
  - Integration of virtual and real worlds
    - Realistic Color, Lighting, Shadowing, Depth integration
    - Interaction of the user with virtual objects, Interaction between virtual objects and the real world
  - Level of abstraction of Virtual Objects
- Propose a collaborative web app?
- Discuss the benefits/drawbacks of our classification with you!
- Add/Remove/Modify criteria based on the discussion held at this workshop!

Thank you!