Modeling Temporal Aspects of Visual and Textual Objects in Multimedia Databases

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Talk Overview

- Introduction;
- Motivation;
- The Multimedia Temporal Data Model
  - basic concepts;
  - composing visual data;
  - the temporal dimension of visual data;
  - integrating visual and textual data;
  - temporal aspects of observations.
- Final Outlines.

Introduction

The integrated management of video, audio, and textual data is a need for several application domains:

- geographical information systems;
- medical information systems;
- video/movie archive systems.

Introduction

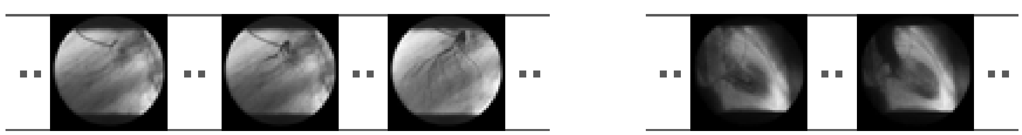
Modeling multimedia information at conceptual and logical levels:

- *Composition of visual data*;
- *Temporal dimension of visual data*;
- *Multimedia data as integration of visual and textual data*;
- *Temporal aspects of textual observations related to visual data*.

A Motivating Application Domain

- Cardiac angiography is a technique adopted to study the situation of coronary vessels (coronary angiography) and of heart functionalities (left ventriculography).

- The result of a cardiac angiography consists of an X-ray movie.



- Diagnoses based on the content of the movie consist of identifying stenoses (i.e., reductions of vessel lumen) and problems in the movement (contraction/relaxation) of the heart.

A Motivating Application Domain

The stored movies can be used in many different ways:

- the physicians could be interested in composing a video, where different movies collected on the same patient can be viewed in sequence, to control the patient's state evolution;

- it could be useful to compose other videos, on the basis of movies from several patients, showing, for didactic/research reasons, different approaches/results in a given patients population.

The Temporal Object-Oriented Data Model

GCH-OODM (Granular Clinical History - Object- Oriented Data Model) is an object-oriented data model extended to consider and manage the valid time of information.

Basic concepts

- *class* (type) and *object*: a database schema consists of a set of classes; objects are created as instances of a class.
  - state (attributes)
  - interface (methods)
- object identity; abstract data types; single inheritance; polymorphism;management of complex objects; persistence

GCH-OODM classes

- the usual types (`char`, `string`, `int`, `real`);
- the usual type constructors (`array`, `list`, `set`, ...);
- the class hierarchy composed by classes `el_time`, `instant`, `duration`, and `interval`
  - `el_time` (elementary time) allows us to model a chronon;
  - `instant` allows us to represent a time point, identified by the granule, i.e. a set of contiguous chronons, containing it;
  - `duration` allows us to model a generic duration, specified at arbitrary granularity;
  - `interval` models a generic interval, i.e. a set of contiguous time points. Notation: `FROM` $<instant>$ `TO` $<instant>$ `FOR` $<duration>$.

The Temporal Object-Oriented Data Model

- GCH-OODM relies on a three-valued logic modeled by the class `bool3`, allowing the management of the uncertainty coming from comparisons between temporal dimensions expressed with different granularities.

- Classes modeling objects having a temporal dimension inherit from the class `Temporal_Object`: the method `valid_interval`() defined for this class, returns an object of the class `interval`, thus allowing one to consider the valid time for that object.

Composing Visual Data

In our multimedia data model, we define three abstraction layers for video data:

- the *physical layer*, where we model the data sequence (stream) coming from an acquisition device;
- the *logical layer*, where we are able to identify meaningful frame sequences into the raw stream;
- the *compositional layer*, where we can associate frame sequences from different streams, to compose videos.

Composing Visual Data

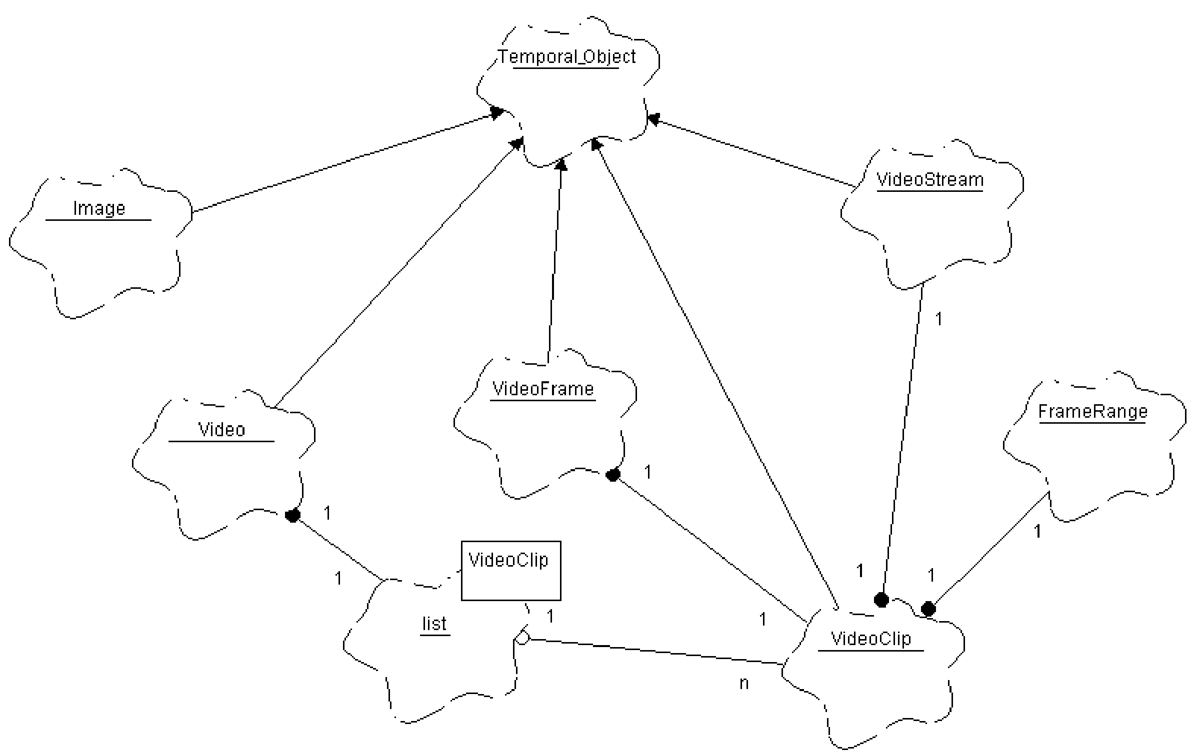
- the class `VideoStream` allows one to store video data, while the class `Image` allows the storage of static images;

- `VideoClip` and `VideoFrame` allow the user to identify suitable subparts into a video stream and to refer to it;

- the class `Video` allows one to create different videos by composing image sequences from different video streams.

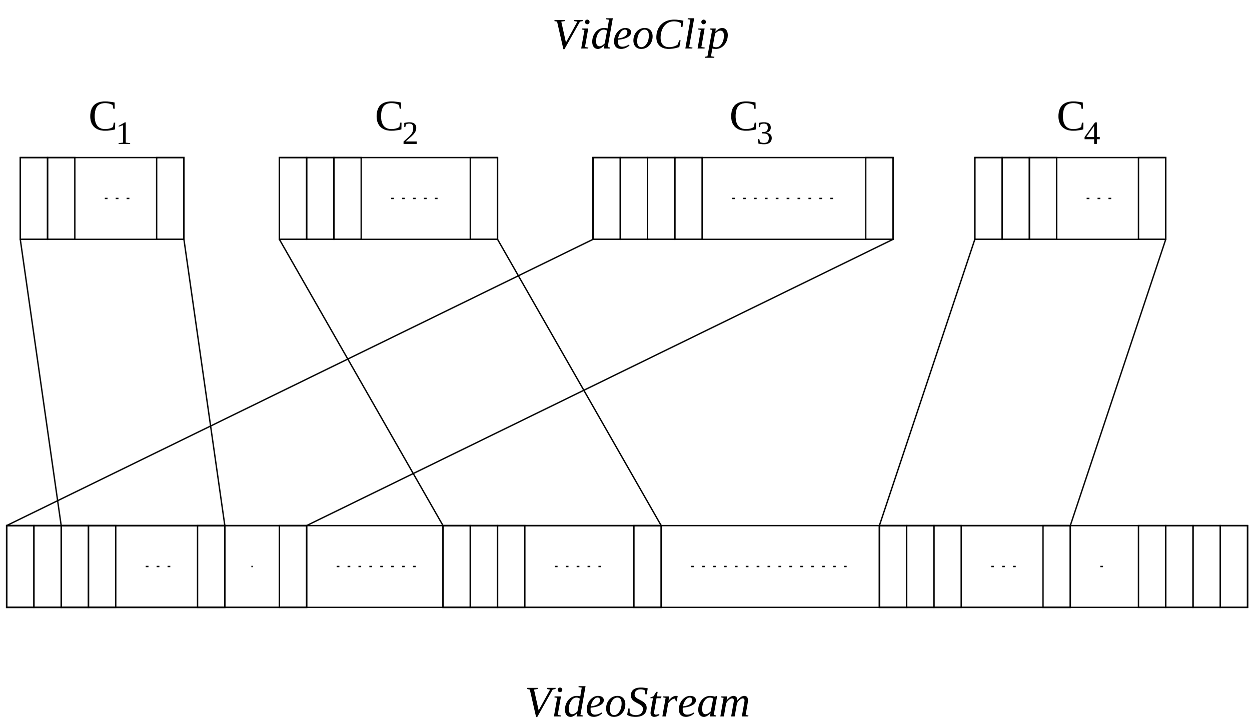
Composing Visual Data

The Booch Class Diagram for Visual Classes



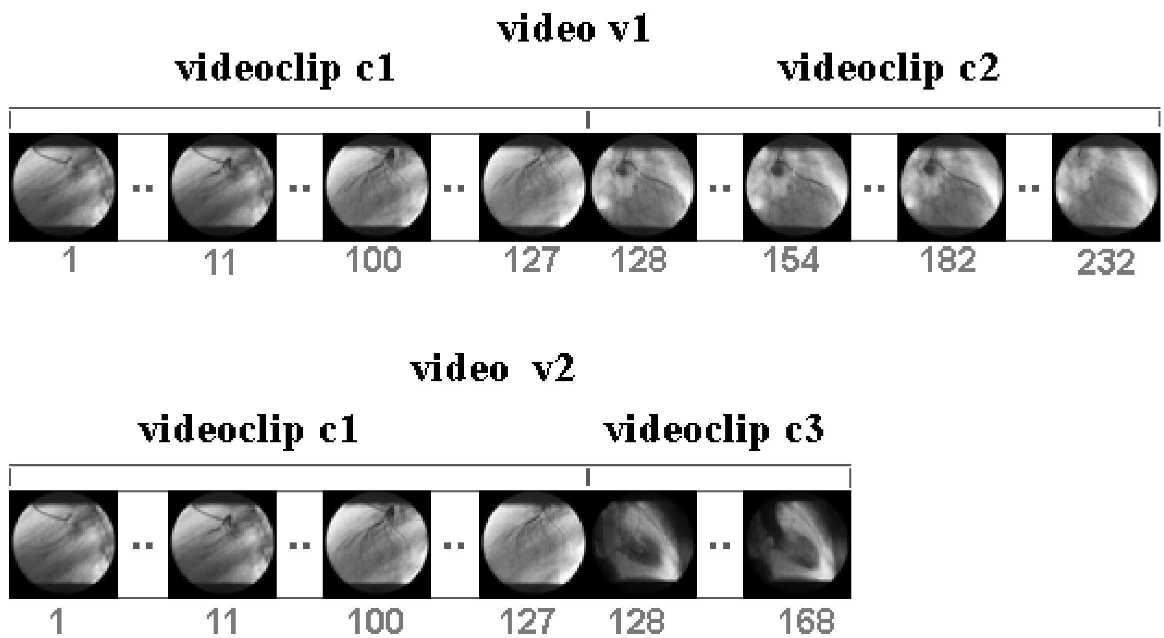
Composing Visual Data

```
class VideoClip : public Temporal_Object {
VideoStream relatedVideoStream();
FrameRange start_end_Frames();
void play();
};
```



Composing Visual Data

```
class Video : public Temporal_Object {
list < VideoClip > videocomposition();
long totalFrames();
.....
.....
void play();
};
```



The Temporal Dimension of Visual Data

- *intrinsic time*: the time we can use to identify some frames inside the frame sequence, on the basis of their distance from the first frame of the sequence;

- *extrinsic time*: the usual valid time, possibly given at different granularities.

The Temporal Dimension of Visual Data

$v = [c_1, \ldots, c_n]$ is an object of the class `Video`;

$c_1, \ldots, c_n$ are objects of the class `VideoClip`;

$I = \{i_1, \ldots, i_n\}$ is the set of valid times of objects $c_1, \ldots, c_n$.

The *valid time* of v is

$vt_v \equiv (vt_v.\texttt{start}(), vt_v.\texttt{end}(), vt_v.\texttt{dur}())$, where:

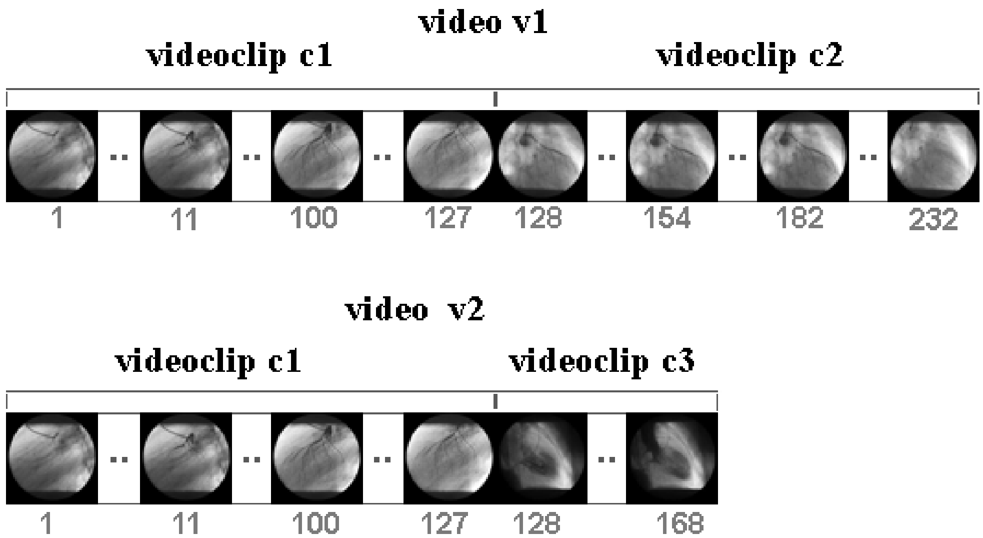
$$vt_v.\texttt{start}().\texttt{inf}() = min(i_j.\texttt{start}().\texttt{inf}()),\ i_j \in I$$
$$vt_v.\texttt{start}().\texttt{sup}() = min(i_j.\texttt{start}().\texttt{sup}()),\ i_j \in I$$

$$vt_v.\texttt{end}().\texttt{inf}() = max(i_j.\texttt{end}().\texttt{inf}()),\ i_j \in I$$
$$vt_v.\texttt{end}().\texttt{sup}() = max(i_j.\texttt{end}().\texttt{sup}()),\ i_j \in I$$

$$vt_v.\texttt{dur}().\texttt{inf}() = max(max(i_j.\texttt{dur}().\texttt{inf}()), (vt_v.\texttt{end}().\texttt{inf}() - vt_v.\texttt{start}().\texttt{sup}())),\ i_j \in I$$
$$vt_v.\texttt{dur}().\texttt{sup}() = max(max(i_j.\texttt{dur}().\texttt{sup}()), (vt_v.\texttt{end}().\texttt{sup}() - vt_v.\texttt{start}().\texttt{inf}())),\ i_j \in I$$

The Temporal Dimension of Visual Data

Example



frame rate = 30 fps

$c1$.relatedVideoStream() returns the videostream $vs1$

$c1$.start_end_Frames() returns $[21, 147]$

$vs1$.valid_interval() returns FROM 98Jul8/13 FOR 20 ss

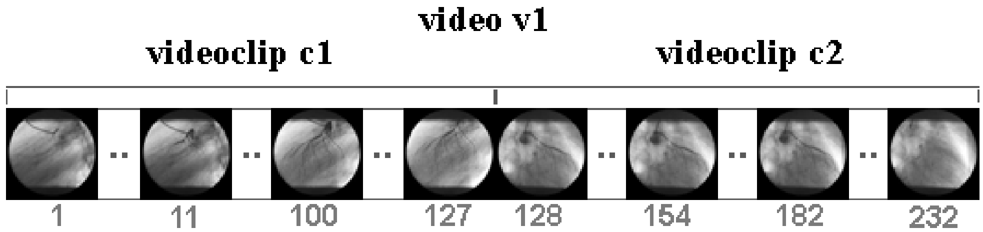
$c3$.relatedVideoStream() returns the videostream $vs3$

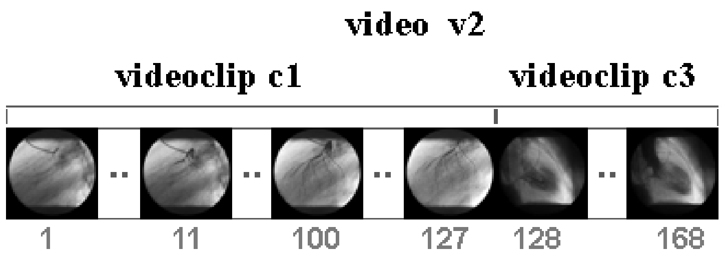
$c3$.start_end_Frames() returns $[1, 41]$

$vs3$.valid_interval() returns FOR 15 ss TO 98Jul8/13 : 15

The Temporal Dimension of Visual Data

Example





$c1$.valid_interval() returns
FROM ≺98Jul8/13 : 00 : 0.66, 98Jul8/14 : 00 : 0.65≻
FOR 4.23 ss

$c3$.valid_interval() returns
FOR 1.36 ss
TO ≺98Jul8/13 : 14 : 46.37, 98Jul8/13 : 15 : 46.36≻

$v2$.valid_interval() returns
FROM ≺98Jul8/13 : 00 : 0.63, 98Jul8/13 : 15 : 44.99≻
TO ≺98Jul8/13 : 14 : 46.37, 98Jul8/14 : 00 : 4.88≻
FOR ≺4.23 ss, 1 hh 0 min 4.22 ss≻

Integrating Visual and Textual Data: Observations

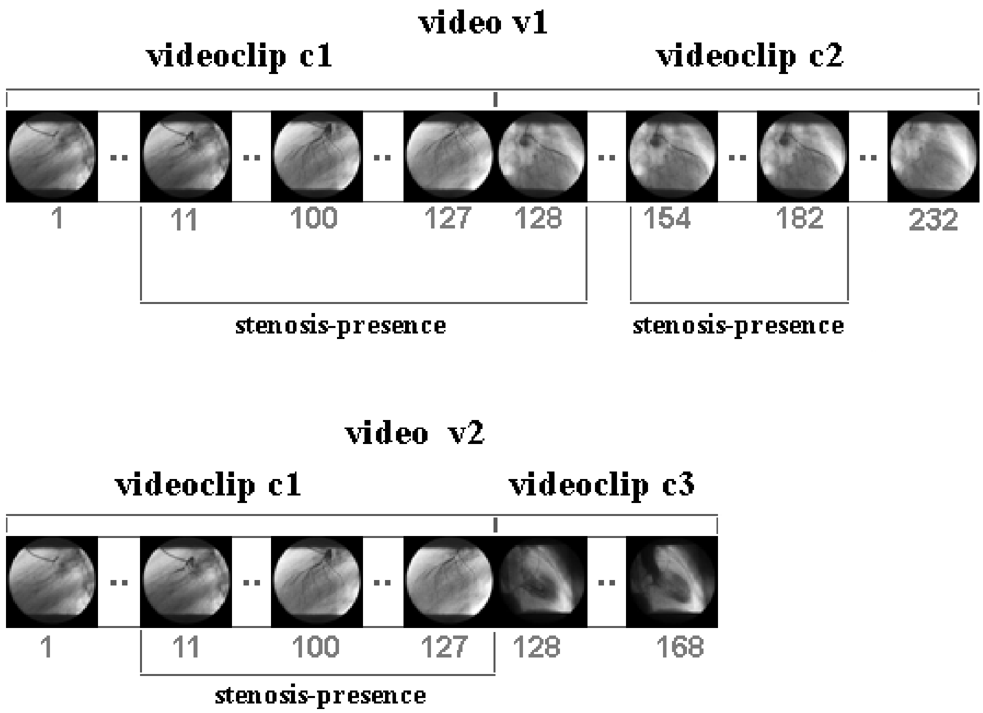
An *observation* is any kind of textual information related to a visual object.

```
class Observation : public Temporal_Object {
string description();
set < Object > relatedObjects();
Role role(Object);
array < Object, Role > obsObjRoles();
array<Video, set< FrameRange>> framesVideo();
set < Image > relatedImages();
set < interval > nonConvexInterval();
};
```

```
class Video : public Temporal_Object {
list < VideoClip > videocomposition();
long totalFrames();
.....
.....
void play();
Tree obsTree();
};
```

Integrating Visual and Textual Data: Observations

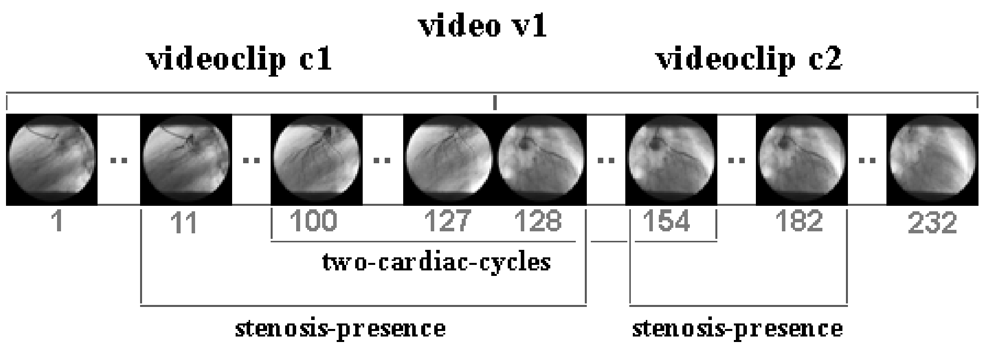
Example



$stenosis\text{-}presence$.framesVideo() returns
$(v1,\ \{[11, 128], [154, 182]\})$ and
$(v2,\ \{[11, 127]\})$

Temporal Aspects of Observations

Dynamic vs. static properties of a video subsequence.



Temporal Aspects of Observations

Types of observation in a multimedia database

- *concatenable observations*;
  if a concatenable observation is valid on the consecutive frame intervals $[i, k]$ and $[k+1, j]$, it is valid on the frame interval $[i, j]$.
  Example: “perfusion of the contrast agent through the coronary vessels”.

- *point-upward observations*;
  if a point-upward observation is valid on the consecutive frame intervals $[i, i]$ and $[i+1, i+1]$, ..., $[i+n, i+n]$ (i.e., on n consecutive frames), it is valid on the frame interval $[i, i+n]$.
  Example:

Temporal Aspects of Observations

Types of observation in a multimedia database

- *weakly-upward-hereditary observations*;
  given a set of n (possibly intersecting) frame intervals $[i_s, i_e]$ over which a weakly-upward-hereditary observation holds, the observation holds also on the intervals obtained as union of the n frame intervals $[i_s, i_e]$.
  Example: “perfusion of the contrast agent through the coronary vessels” is weakly-upward too.

- *downward-hereditary observations*;
  a downward hereditary observation holding on a frame interval $[i_s, i_e]$ holds on any frame interval $[j_s, j_e]$, where $i_s \leq j_s \wedge j_e \leq i_e$.
  Example: “the contrast agent highlights less than half of the left coronary tree”.

Temporal Aspects of Observations

Types of observation in a multimedia database

- *liquid observations*;

  those observations which are both downward and point-upward hereditary, are termed as liquid.

  Example: “presence of a stenosis”.

- *solid observations*;

  a solid observation holding on a frame interval $[i_s, i_e]$ cannot hold on any frame interval $[j_s, j_e]$, for which $(i_s \leq j_s \wedge j_s \leq i_e) \vee (i_s \leq j_e \wedge j_e \leq i_e)$.

  Example: “exactly a cardiac cycle, from the systole (empting phase) to the diastole (filling phase)”.

Temporal Aspects of Observations

Types of observation in a multimedia database

- *gestalt observations*;

  a gestalt observation holding on a frame interval $[i_s, i_e]$ cannot hold on any frame interval $[j_s, j_e]$, for which $(i_s \leq j_s \wedge j_e \leq i_e) \vee (j_s \leq i_s \wedge i_e \leq j_e)$.

  Example: “two cardiac cycles”.

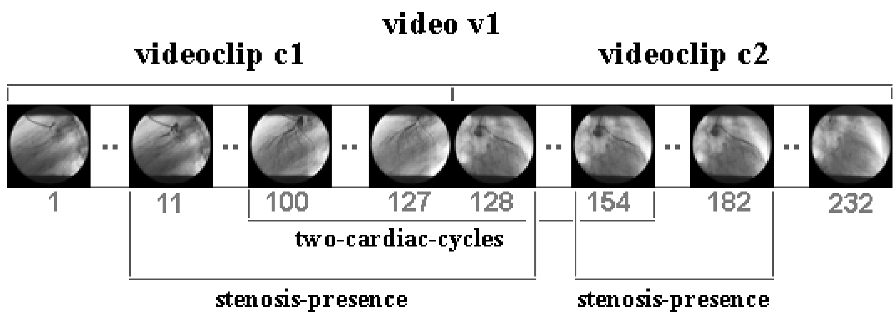
- *disjointed observations*;

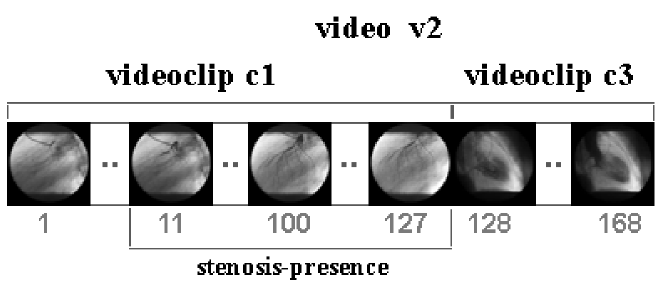
  if a disjointed observation is associated to a frame interval $[i_s, i_e]$, it cannot be associated to any interval $[j_s, j_e]$ such that: $j_s \leq i_s \leq j_e \leq i_e \vee i_s \leq j_s \leq i_e \leq j_e$.

  Example:

Temporal Aspects of Observations

```
class Observation : public Temporal_Object {
string description();
........;
........;
bool3 is_in(Video, FrameRange);
bool3 is_valid(Video, FrameRange);
};
```





stenosis-presence.is_in($v1$, [124,128]) returns True
stenosis-presence.is_valid($v2$, [124,128]) returns True

two-cardiac-cycles.is_in($v1$, [100,110]) returns True
two-cardiac-cycles.is_valid($v1$, [100,110]) returns False
two-cardiac-cycles.is_valid($v1$, [100,154]) returns True

Temporal Aspects of Observations

o is an object of the class `Observation`;
$I = \{i_1, i_2, \ldots, i_n\}$ the set of time intervals related to o by the associations between o and several frame intervals of different videos.

The *valid time* of o is
$vt_o \equiv (vt_o.\texttt{start}(), vt_o.\texttt{end}(), vt_o.\texttt{dur}())$, where:

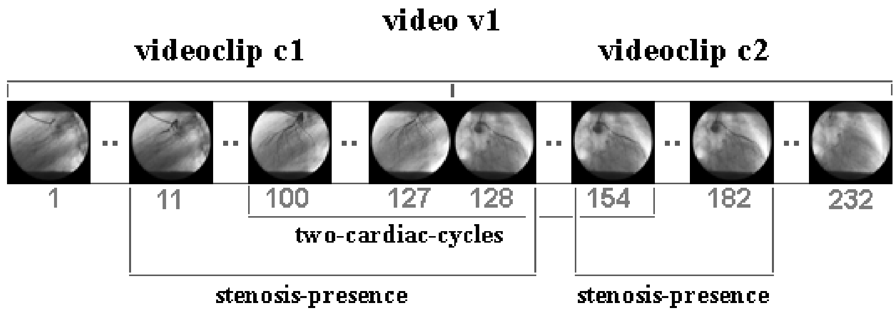
$$vt_o.\texttt{start}().\texttt{inf}() = min(i_j.\texttt{start}().\texttt{inf}()),\ i_j \in I$$
$$vt_o.\texttt{start}().\texttt{sup}() = min(i_j.\texttt{start}().\texttt{sup}()),\ i_j \in I$$

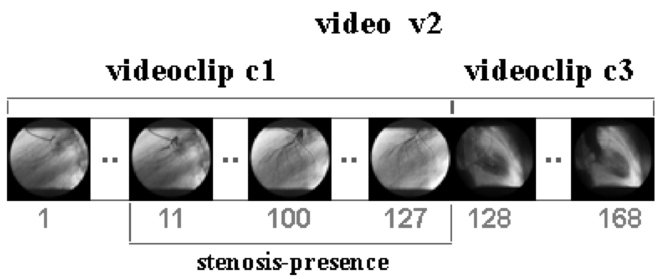
$$vt_o.\texttt{end}().\texttt{inf}() = max(i_j.\texttt{end}().\texttt{inf}()),\ i_j \in I$$
$$vt_o.\texttt{end}().\texttt{sup}() = max(i_j.\texttt{end}().\texttt{sup}()),\ i_j \in I$$

$$vt_o.\texttt{dur}().\texttt{inf}() = max(max(i_j.\texttt{dur}().\texttt{inf}()), (vt_o.\texttt{end}().\texttt{inf}() - vt_o.\texttt{start}().\texttt{sup}())),\ i_j \in I$$
$$vt_o.\texttt{dur}().\texttt{sup}() = max(max(i_j.\texttt{dur}().\texttt{sup}()), (vt_o.\texttt{end}().\texttt{sup}() - vt_o.\texttt{start}().\texttt{inf}())),\ i_j \in I$$

Temporal Aspects of Observations

Example





Intervals related to $stenosis$-$presence$:

FROM $\prec$98Jul8/13 : 00 : 0.99, 98Jul8/14 : 00 : 0.98$\succ$
FOR 3.9ss (from clip $c1$ in videos $v1$ and $v2$);
FROM $\prec$98Aug10/15 : 30 : 1.63, 98Aug10/15 : 31 : 1.62$\succ$
FOR 0.03 ss (from clip $c2$ in video $v1$);
FROM $\prec$98Aug10/15 : 30 : 2.49, 98Aug10/15 : 31 : 2.48$\succ$
FOR 0.96 ss (from clip $c2$ in video $v1$).

$stenosis$-$presence$.valid_interval() returns

FROM $\prec$98Jul8/13 : 00 : 0.99, 98Jul8/14 : 00 : 0.98$\succ$

TO $\prec$98Aug10/15 : 30 : 3.45, 98Aug10/15 : 31 : 3.44$\succ$

Temporal Aspects of Observations

Given the set $I = \{i_1, i_2, \ldots, i_n\}$ of intervals related to the frame interval $[j, k]$ of a video, given the set $\{vt_1, vt_2, \ldots, vt_m\}$ of valid times of m temporal objects involved in the considered observation, we can associate the observation to the frame interval $[j, k]$ of the video, only if

$\forall vt_z \ (z = 1, \ \ldots, \ m) \ \forall i_w \ (w = 1, \ \ldots, \ n)$ $i_w.\mathtt{DURING}(vt_z)$ returns `True`

Example

$stenosis\text{-}presence.\mathtt{relatedObjects}()$ returns $\{sten1\}$

$stenosis\text{-}presence.\mathtt{valid\_interval}().$
$\quad\quad \mathtt{DURING}\ (sten1.\mathtt{valid\_interval}())$
must return `True`.

Final Outlines

- *Composition of temporal visual data*.
  - three-layer approach to compose videos;
  - valid time of visual objects at different granularities and/or with indeterminacy.

- *Integration of temporal visual and textual data*.
  - taxonomy for observations based on their temporal features;
  - valid time of observations and constraints with valid times of other involved database objects.

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