General Medical Image Description Grammar for Images of the Ocular Fundus

Toward A Generic Description Model for Medical Images: The case of the Ocular Fundus

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Universal Grammar

❖Universal Grammar is a theory of knowledge based on the internal structure of the human mind.

❖Universal Grammar for language is a system of *principles*, *conditions*, and *rules* that form the *essence* of human language. Universal Grammar for an image is a system of *principles*, *conditions*, and *rules* that form the *essence* of human vision.

❖In language, the principle of structure dependency relies on structural relationships, not sequence of words.

❖A sentence can be broken down into *component parts* and *relationships*.

❖In a medical image, the principle of object dependency relies on the identity and relationship of objects, not on simple features such as color.

❖A medical image can be broken down into its *component parts* and their *relationships*.

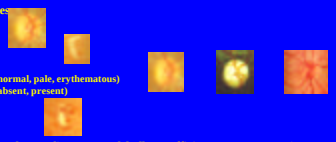
What is an Image Description Model?

❖An image description model is a mathematically sound way to describe any image in such a way that it represents the *essential elements* of the image content.

❖The components of this description can comprise *contents*, *location*, and *time*.

❖The representation describes

- Relevant objects
  - Optic nerve
  - Cotton wool spot
- Properties of the objects
  - Optic nerve color (normal, pale, erythematous)
  - Cotton wool spot (absent, present)
- Relationships between object
  - Proximity
  - Surrounding



❖An image description produced according to a model allows *efficient storage*, permits a user to *query its properties* in arbitrary manner and helps to *create rules* to *automatically classify* and *make inferences* from the images.

The Principles for Describing an Image

❖The viewed image is a partial *projection* of a known geometry (part of a sphere for the ocular fundus projected to a flat disk). So the captured image should be *situated* with respect to the known geometry.

❖The image *geometry* can be expressed in terms of different coordinate reference systems depending on the need of the user. Ophthalmologists may use *polar* coordinates *centered* on the *fovea* or the *optic nerve*. Computer images have pixels in *Cartesian* coordinates. The image coordinates should be mathematically *transformable* from one system to another.

❖The objects in a medical image can be subclassified as *anatomical structures* and a variable number of *lesions*.

❖Different objects and measurements made on the objects can be associated with different levels of *uncertainty*. This uncertainty must be characterized to answer queries and make inferences reliably.

❖The measurement of object features may or may not be sharply delineated in the image. An object descriptor must allow variable *degrees of specificity* in describing the spatial extent and the fidelity of measurements made on them.

❖*Spatial locations* of objects and *spatial relationships* between objects need to be directly represented or inferred; for example is object1 around object2, or does a ring of exudates surround the macula?.

❖Since many of the objects are lesions and anomalies, their *severity* must be expressed, by a feature descriptor, the area of spread, the pattern of distribution, or even a qualitative description of the affected region.

❖The description should be generated automatically whenever possible. In some cases, we can use image analysis algorithms to extract objects and their properties. In these cases, the description can be computed automatically.

Our goals

❖To define an image description model that is sufficiently generic to become a *standard* for all *medical images*.

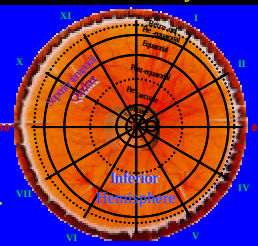
❖To describe any collection of static medical image taken for purposes of *diagnosis* or *prediction*.

❖To capture in the description sufficient details about the imaging process, observed features, and functional *characterization of the patient's state*.

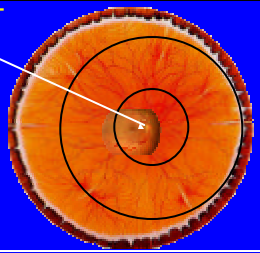
❖To capture the *change* that occurs between two images of the same patient and relate this description to the physiological or disease *process that causes the change*.

❖To make such a description of an image or change between images an integral part of a patient's *electronic medical record*.

Foveal Coordinate System



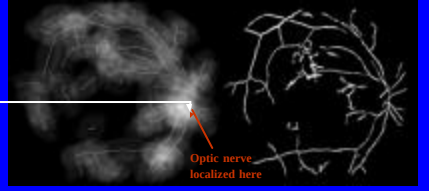
Papillary Coordinate System



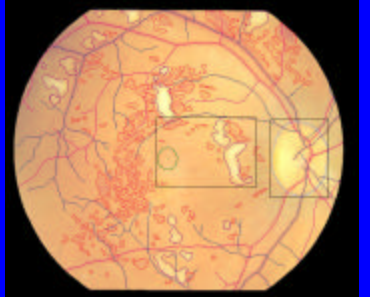
Steps in Identifying Component Parts

For every image of the domain…

extract some essential objects, such as the optic nerve, fovea, and blood vessels…



extract other objects of interest, classify them automatically or manually, and make measurements



Objects extracted include optic nerve, arteries, veins, fovea, cotton-wool spot, hemorrhages.

Informal Example Description

Object class
- ***Object***
  - *Location*
  - *Measurement (= severity when not indicated)*
    - *Values*

⇒

Macular lesions
- Macular star
  - Macular zone
  - Severity
    - Absent
    - Incomplete
    - Complete

or

Blood vessels
- Artery
  - Artery diameter
    - Extreme generalized narrowing, global
    - Moderate generalized narrowing, global
    - Moderate generalized narrowing, branch or single
    - Focal narrowing in 1 or more artery segments
    - Normal (absence of other states)
    - Generalized dilation, tortuosity , branch or single
    - Generalized dilation, tortuosity , global
    - Extremely dilated, branch or global

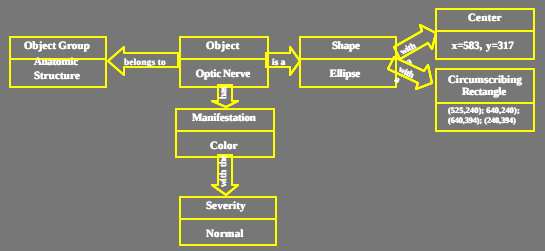
Why a Formal Grammar?

A grammar is a *deconstruction* mechanism, where sentences are broken up into clauses, phrases, words, such that the resultant structure helps to unambiguously localize and identify the role of each element in defining the semantics of the sentence. A formal image grammar is an equivalent mechanism to create the semantics of the content of an image.

Why XML?

Our Description Model is based on *tree-structured* data, implemented in XML. We chose XML, because it platform-independent, self-describing, allows structural variations, is an emerging standard for data interchange, and is extensible to any domain of application.

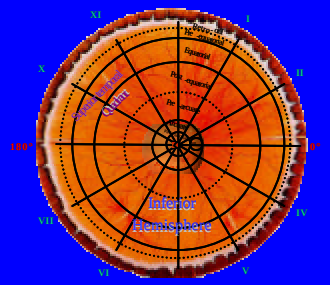
Example of Grammar for Fundus Images



The Formal Description Grammar for Storage and Retrieval

```
<!ELEMENT image (patient_metadata|photo_metadata|object_group|area_of_interest)* >
<!ELEMENT patient_metadata (first_name|last_name|gender|age|origin|location|file_number|
image_file_number|diagnosis)* >
<!ELEMENT first_name (#PCDATA)* >
<!ELEMENT last_name (#PCDATA)* >
<!ELEMENT gender (#PCDATA)* >
<!ELEMENT age (#PCDATA)* >
<!ELEMENT origin (#PCDATA)* >
<!ELEMENT location (#PCDATA)* >
<!ELEMENT file_number (#PCDATA)* >
<!ELEMENT image_file_number (#PCDATA)* >
<!ELEMENT diagnosis (#PCDATA)* >
<!ELEMENT photo_metadata (instruments|image_properties)* >
<!ELEMENT instruments (camera)* >
<!ELEMENT camera (name|field_of_view|magnification)* >
<!ELEMENT name (#PCDATA)* >
<!ELEMENT field_of_view (#PCDATA)* >
<!ELEMENT magnification EMPTY >
 <!ELEMENT image_properties (size)* >
<!ELEMENT size (#PCDATA)* >
<!ELEMENT object_group (eye|object|object_group)* >
<!ATTLIST object_group type CDATA #IMPLIED>
<!ATTLIST object_group severity CDATA #IMPLIED>
<!ELEMENT eye (#PCDATA)* >
<!ELEMENT object (#PCDATA|shape|manifestations|rim|cup|vein|capillaries|
hemorrhage|cotton_wool_spot|artery)* >
<!ELEMENT shape (#PCDATA|center|circumscription)* >
<!ELEMENT center (coordinates)* >
<!ELEMENT coordinates EMPTY >
<!ELEMENT circumscription EMPTY >
<!ELEMENT manifestations (color|objects|collaterals|swelling|hemorrhages|disc_neovascularization|
diameter|tortuosity|bv_specular_reflex|A_V_xing_changes|sheathing|
macroaneurism |emboli)* >
<!ELEMENT color (#PCDATA)* >
<!ELEMENT objects (#PCDATA)* >
<!ELEMENT rim (shape)* >
<!ELEMENT cup (#PCDATA)* >
<!ELEMENT collaterals (#PCDATA)* >
<!ELEMENT swelling (#PCDATA)* >
<!ELEMENT hemorrhages (#PCDATA)* >
<!ELEMENT disc_neovascularization (#PCDATA)* >
<!ELEMENT area_of_interest (#PCDATA|object_group)* >
<!ELEMENT vein (#PCDATA|segment)* >
<!ELEMENT segment (shape_point|manifestations)* >
<!ELEMENT shape_point EMPTY >
<!ELEMENT diameter (#PCDATA)* >
<!ELEMENT tortuosity (#PCDATA)* >
<!ELEMENT bv_specular_reflex (#PCDATA)* >
<!ELEMENT A_V_xing_changes (#PCDATA)* >
<!ELEMENT capillaries (telangiectasis)* >
<!ELEMENT telangiectasis (#PCDATA)* >
<!ELEMENT hemorrhage (boundary|size)* >
<!ELEMENT boundary EMPTY >
<!ELEMENT cotton_wool_spot (boundary|size)* >
<!ELEMENT artery (segment)* >
<!ELEMENT sheathing (#PCDATA)* >
<!ELEMENT macroaneurism (#PCDATA)* >
<!ELEMENT emboli (#PCDATA)* >
```

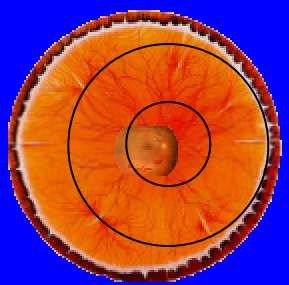
Foveal Coordinate System



Example Rules for Object Localization

```
If (Not(Optic_nerve.Visible))
        Optic_nerve = approximate (fovea, 3300, 7.4°)
Papillary_zone = new Circle (center= (Optic_nerve.Center.X, 0),  radius=1000)
Perimacular_zone = new Circle(center=(0,0), radius=Optic_nerve.Center.X-1000)
Arcuate_zone = new Circle(center=(0,0), radius= Optic_nerve.Center.X+1000)
If (Equatorial_zone.visible)
        Equatorial_zone = new Circle(user_defined_points)
Clock_zone1 = new Segment(center=(0,0), angle1=0°, angle2=30°)
 .....
Clock-zone12 = new  Segment(center=(0,0), angle1=330°, angle2=360°)
For each Clock_zone
        For each Circular-zone
                new Zone = Intersection(Clock_zone, Circular_zone)
        Next
Next
// determine whether a particular requested object is on one of the defined zones
For each object
        new Location = Select(set ="Zones", relation="Intersect")
Next
```

Papillary Coordinate System



Conclusion

The data so stored can be retrieved by a user or a client program, such as an inference program . Or we can map the database description, as in an electronic medical record, into a symbolic image.