Tools for Image Retrieval in Large Multimedia Databases

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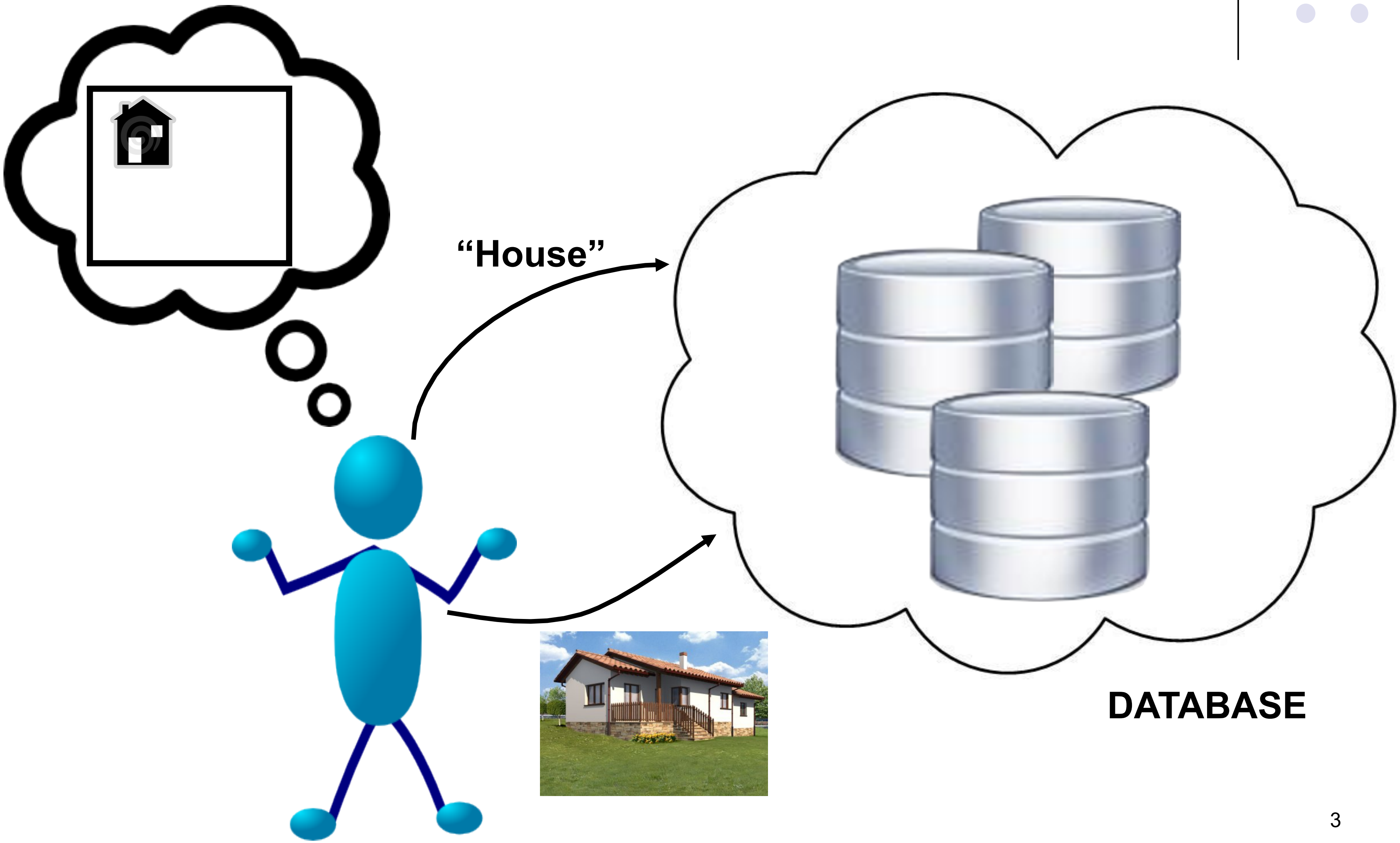
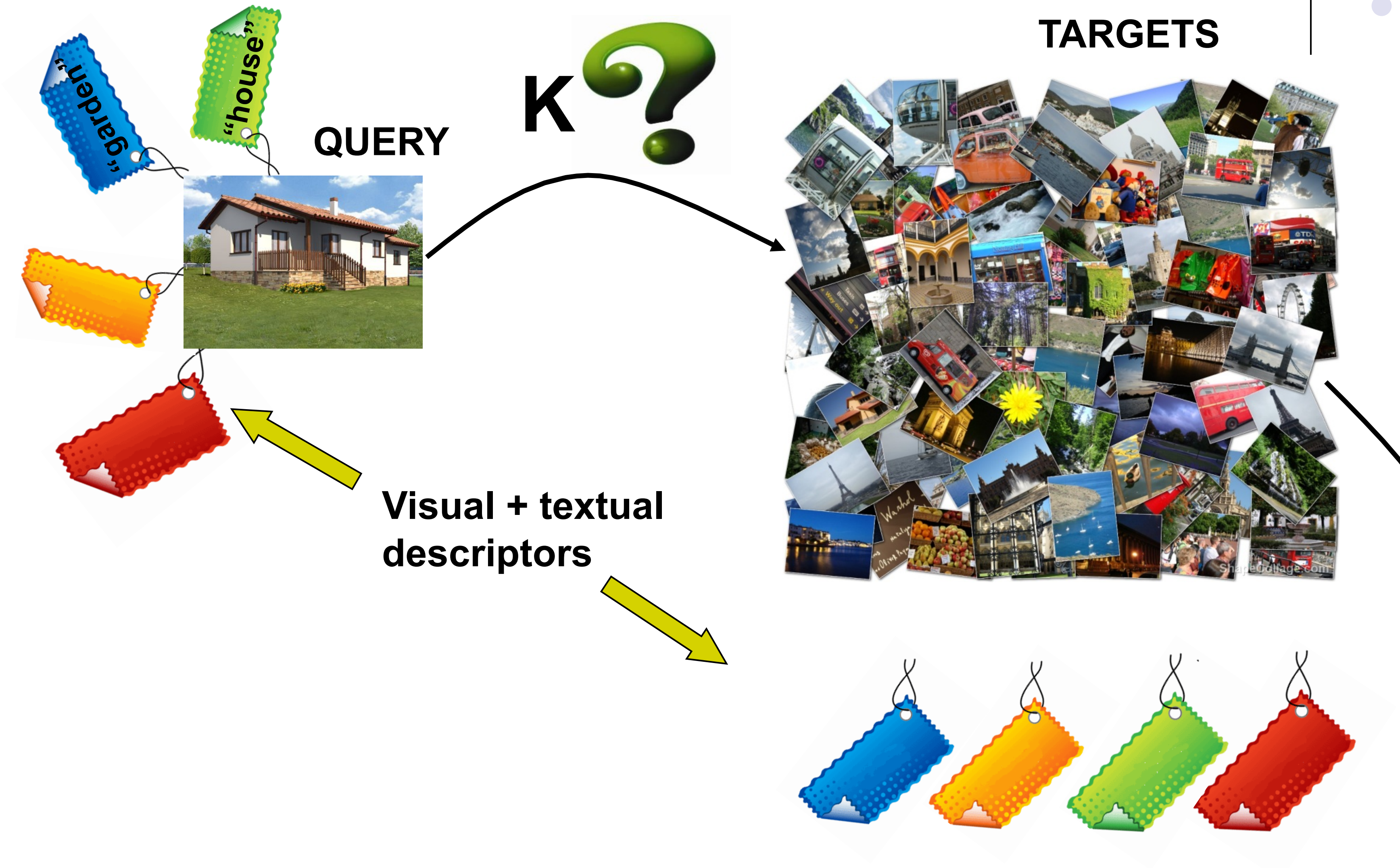
Index

- **Identifying the problem**
- State of art: indexing techniques
- State of art: Hierarchical Cellular Tree (HCT)
- Modifications to the original HCT
- Experimental results
- Implemented tools
- Conclusions and future work lines

Identifying the problem (I)



Identifying the problem (II)



Identifying the problem (III)

- K nearest neighbor problem
- Solution: Sequential scan
  - **Drawback**: Computational time for large databases (10 s for a 200,000 elements)
- Approximate K nearest neighbor problem
  - **Indexing techniques**

Requirements of the solution

- Dynamic approach
  - Multimedia databases are not static
  - Insertions and deletions
- High dimensional feature spaces
  - “curse of dimensionality” problem
  - MPEG-7 visual descriptors are high-dimensional feature vectors

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Indexing techniques (I)

- Hierarchical data structures
  - Spatial Access Methods (SAMs)
    - K-d tree, R-tree, R*-tree, TV-tree, etc.
    - **Drawbacks**:
      - Items have to be represented in an N-dimensional feature space
      - Dissimilarity measure based on a L_p metric
      - SAMs do not scale up well to high dimensional spaces

Indexing techniques (II)

- Hierarchical data structures
  - Metric Access Methods (MAMs)
    - VP-tree, MVP-tree, GNAT, M-tree, etc.
    - More general approach than SAMs
      - Assuming only a similarity distance function
    - MAMs scale up well to high dimensional spaces
    - **Drawbacks**:
      - Static MAMs do not support dynamic changes
      - Dependence on pre-fixed parameters

Indexing techniques (III)

- Locality Sensitive Hashing
  - It uses hash functions
  - Nearby data points are hashed into the same bucket with a high probability
  - Points faraway are hashed into the same bucket with a low probability
  - **Drawback**:
    - It does not solves the K nearest neighbor problem, but the Є-near neighbor problem.

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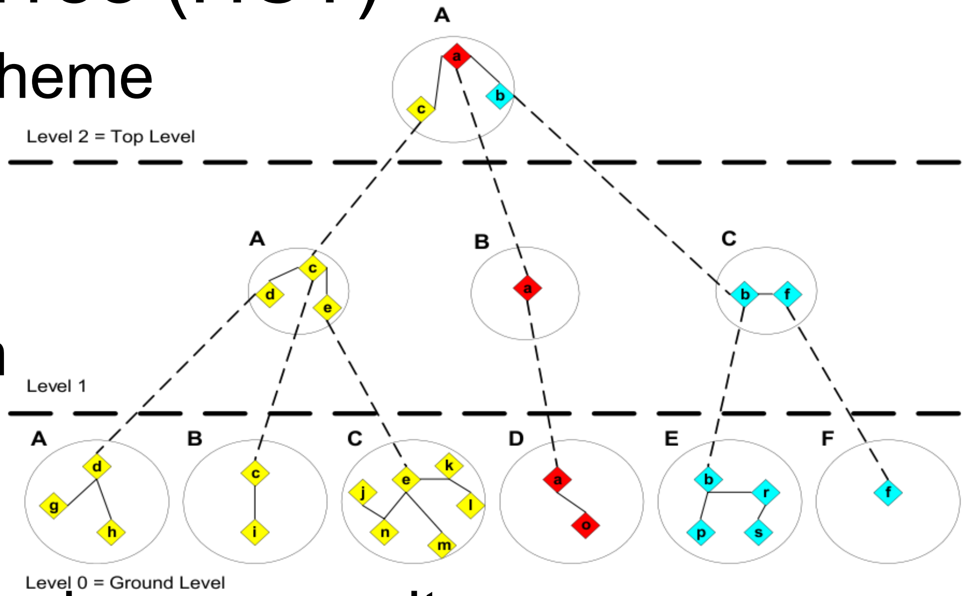
Solution adopted

- Hierarchical Cellular Tree (HCT)
  - MAM-based indexing scheme
  - Hierarchical structure
  - Self-organized tree
  - Incremental construction in a bottom-up fashion
  - Unbalanced tree

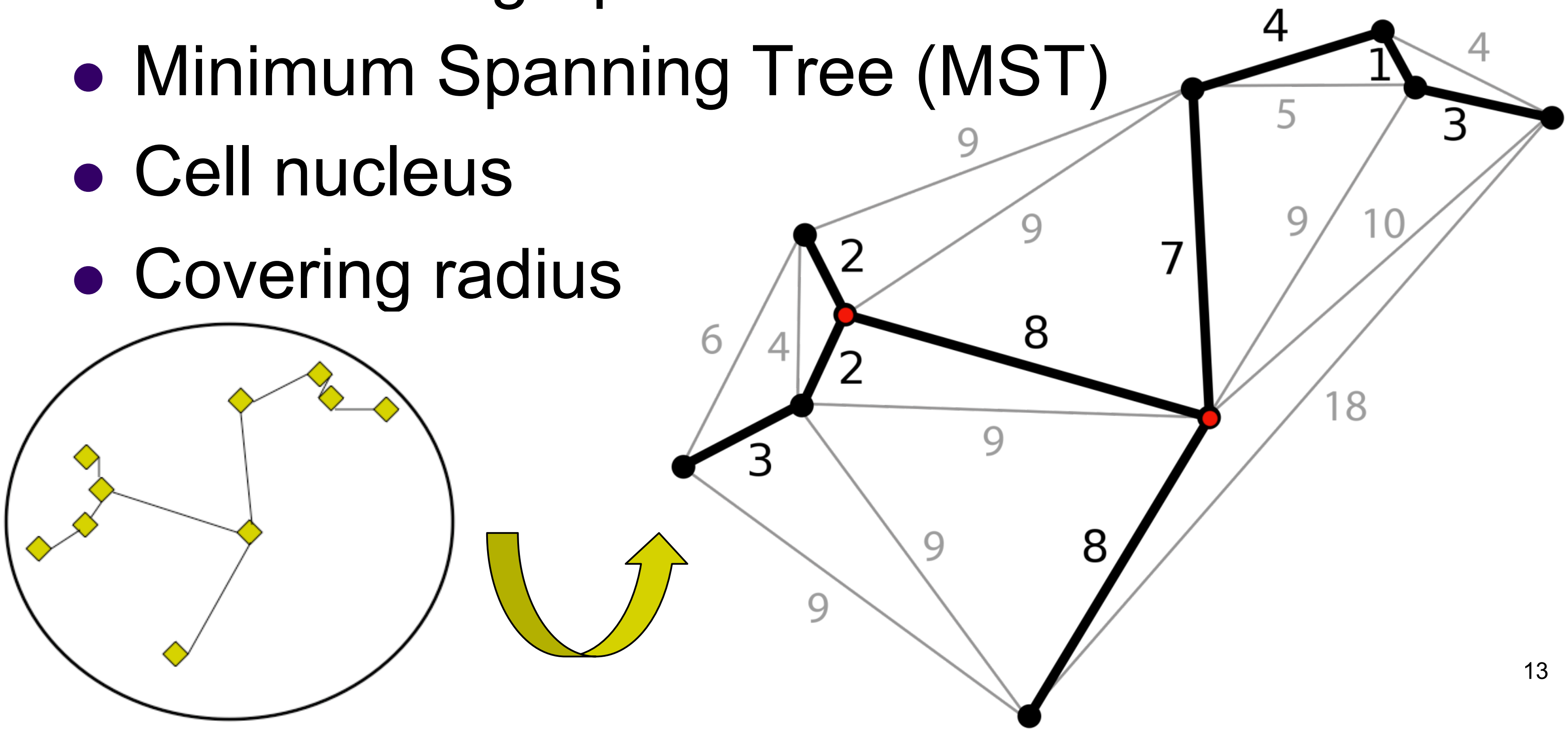


  - Not dependence on a maximum capacity
  - Preemptive cell search algorithm for insertion
  - Dynamic approach

[KG07] S. Kiranyaz and M.Gabbouj, *Hierarchical Cellular Tree: An efficient indexing scheme for content-based retrieval on multimedia databases*.

HCT: Cell Structure (I)

- Basic container structure
- Undirected graph
- Minimum Spanning Tree (MST)
- Cell nucleus
- Covering radius

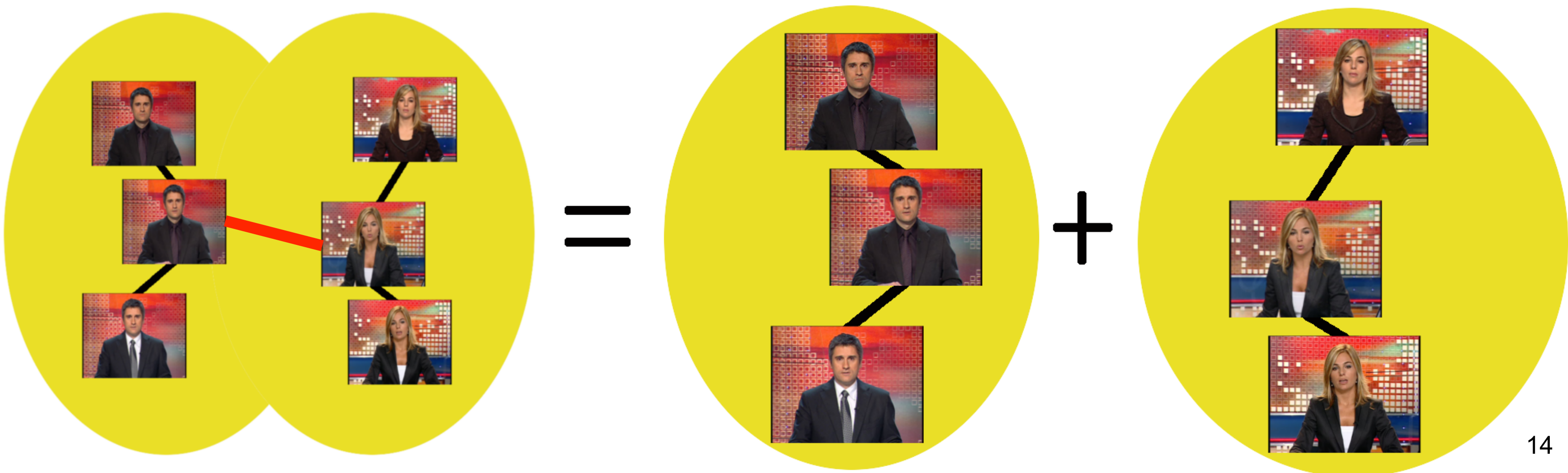


HCT: Cell Structure (II)

- Cell compactness

$$CF_C = f(\mu_C, \sigma_C, r_C, max(w_C), N_C) \geq 0$$

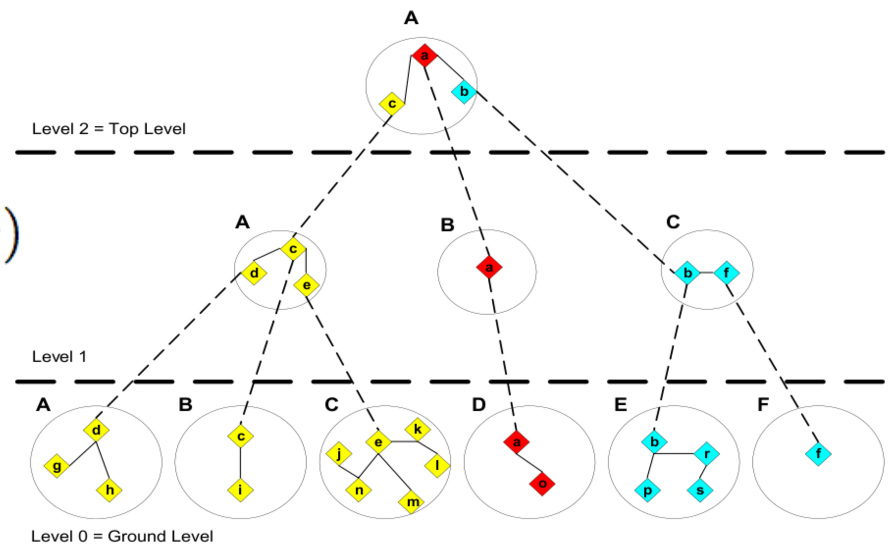
- Maturity size
- Mitosis operation



HCT: Level Structure

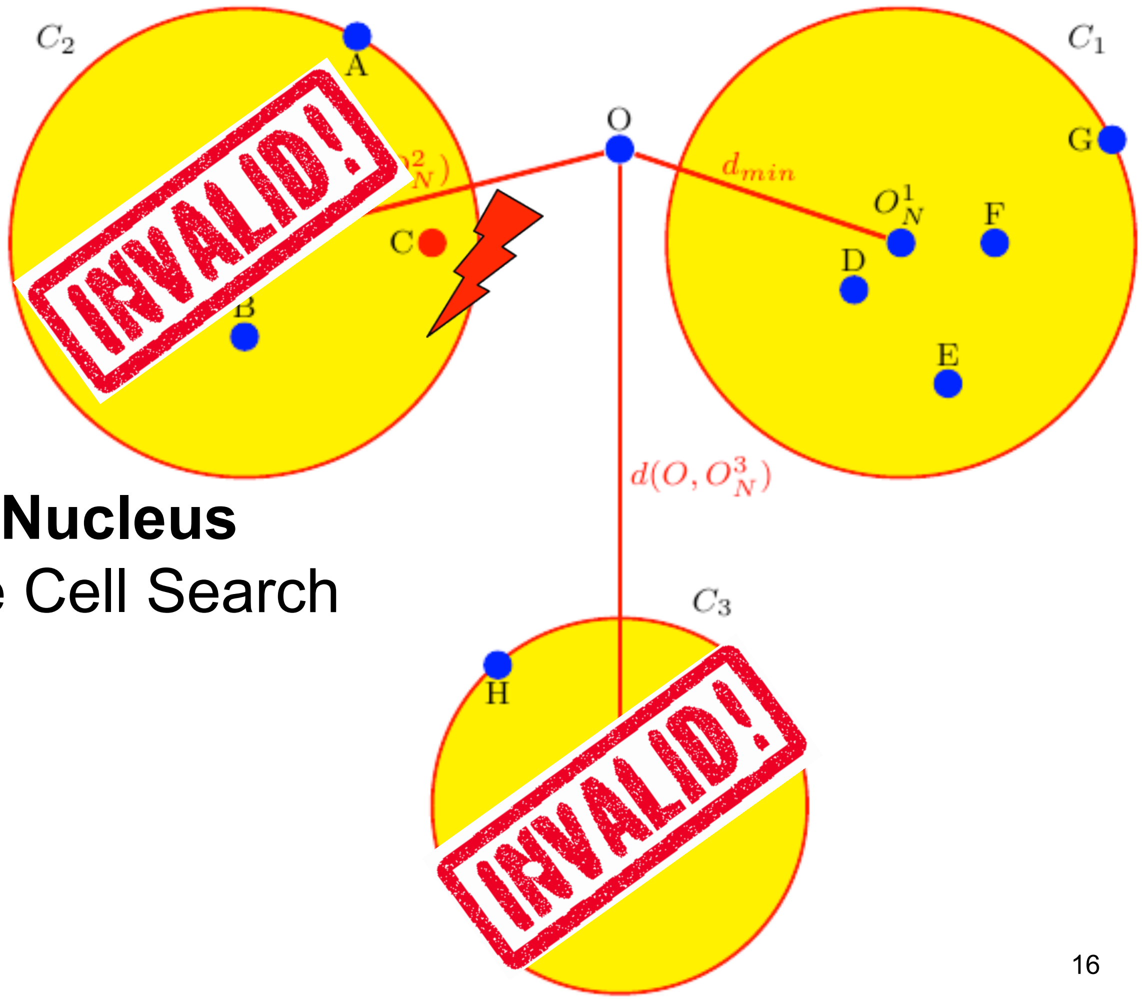
- Representatives for each cell from the lower level
- Responsible for maximizing the compactness of its cells
- Compactness threshold

$$CThr_L = \frac{1}{k_0} Median(CF_C | \forall C \epsilon S_M)$$



HCT Operations (I)

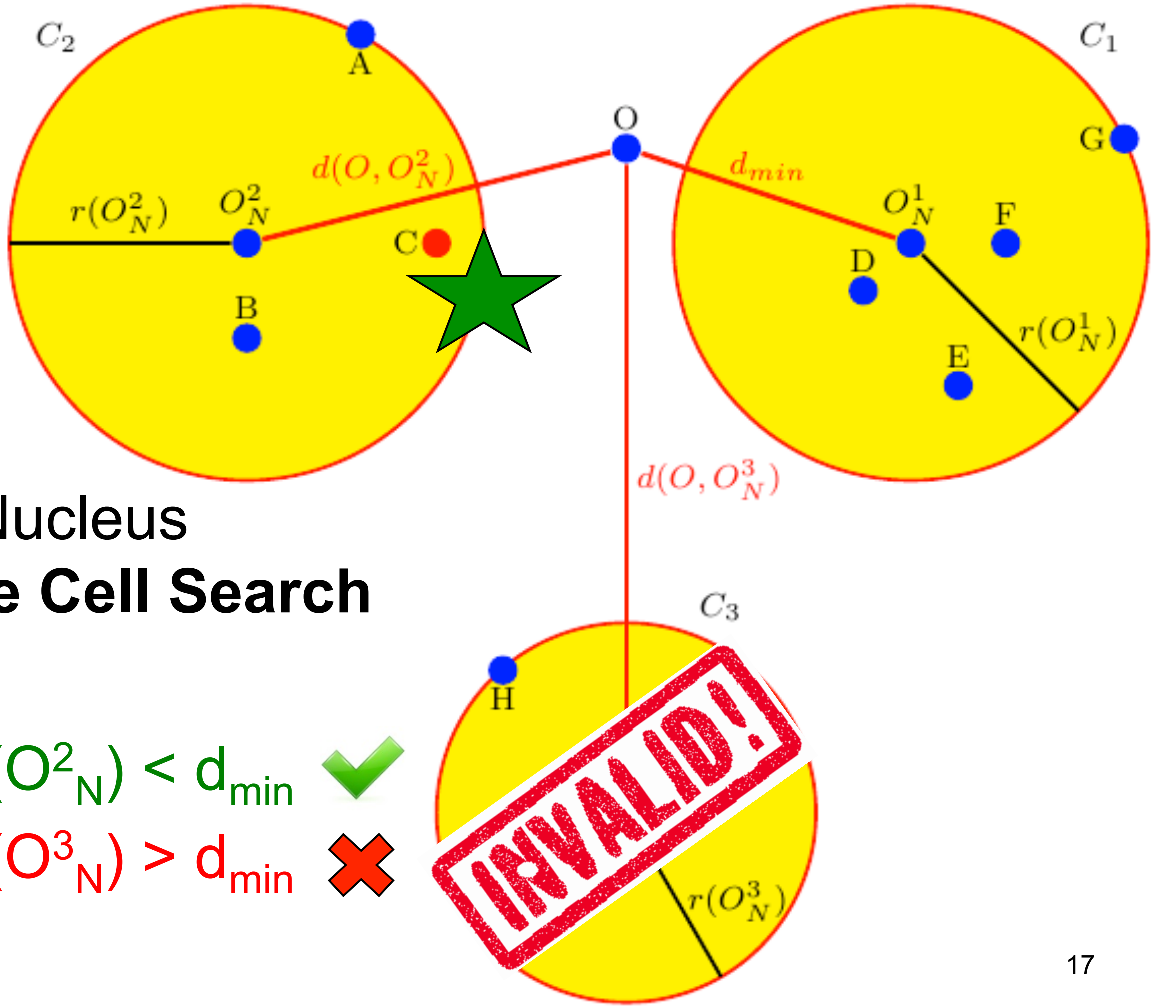
- Item insertion
  - Find the most suitable cell



  - **Most Similar Nucleus** vs Preemptive Cell Search

HCT Operations (II)

- Item insertion
  - Find the most suitable cell



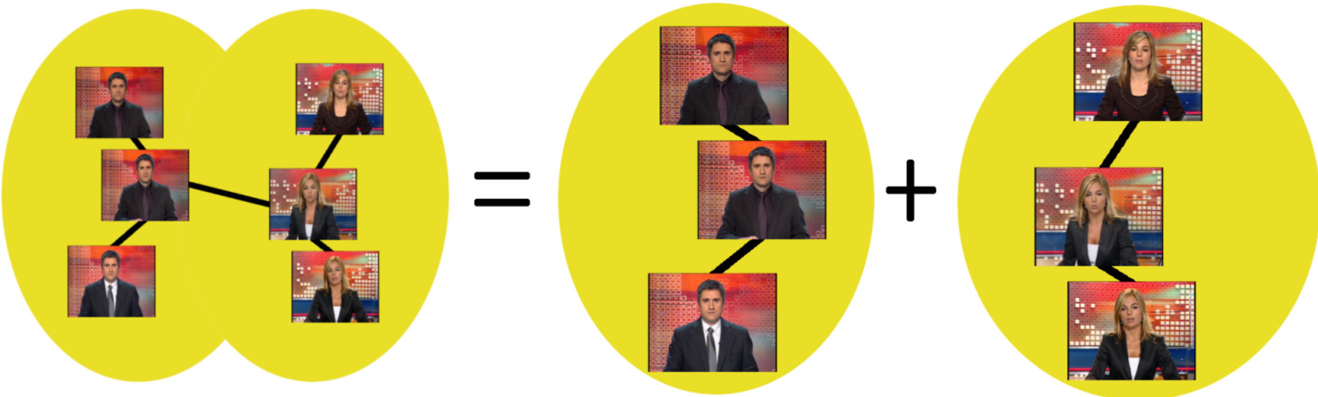
- Most Similar Nucleus vs **Preemptive Cell Search**

C_2: $d(O,O^2_N) - r(O^2_N) < d_{min}$ ✔

C_3: $d(O,O^3_N) - r(O^3_N) > d_{min}$ ✘

HCT Operations (III)

- Item insertion
  - Find the most suitable cell
  - Append the element
  - Generic post-processing check
    - Mitosis operation
    - Nucleus change

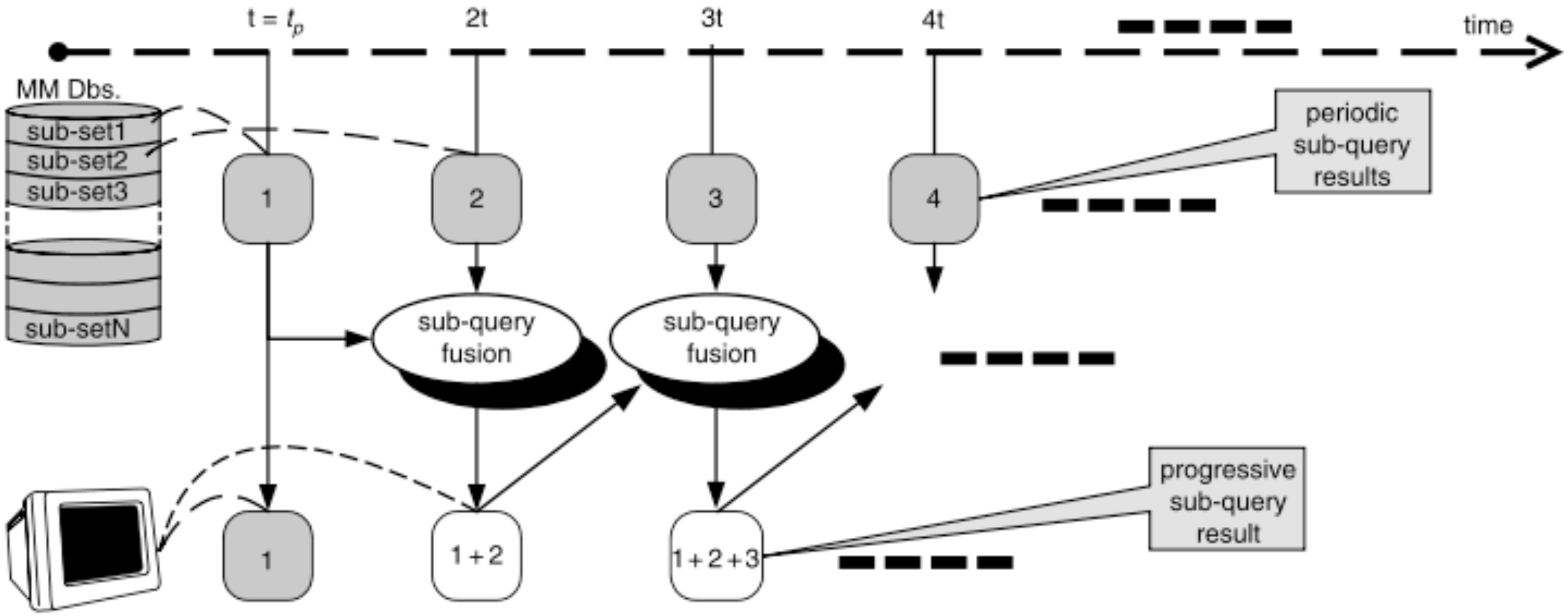


HCT Operations (IV)

- Item removal
  - Cell search algorithm not required
  - Remove the element
  - Generic post-processing check
    - Mitosis operation
    - Nucleus change

HCT: Retrieval scheme

- Progressive Query
  - Periodical subqueries over database subsets
  - Query Path formation
    - Based on Most Similar Nucleus
  - Ranking agreggation



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- **Modifications to the original HCT**
- Experimental results
- Implemented tools
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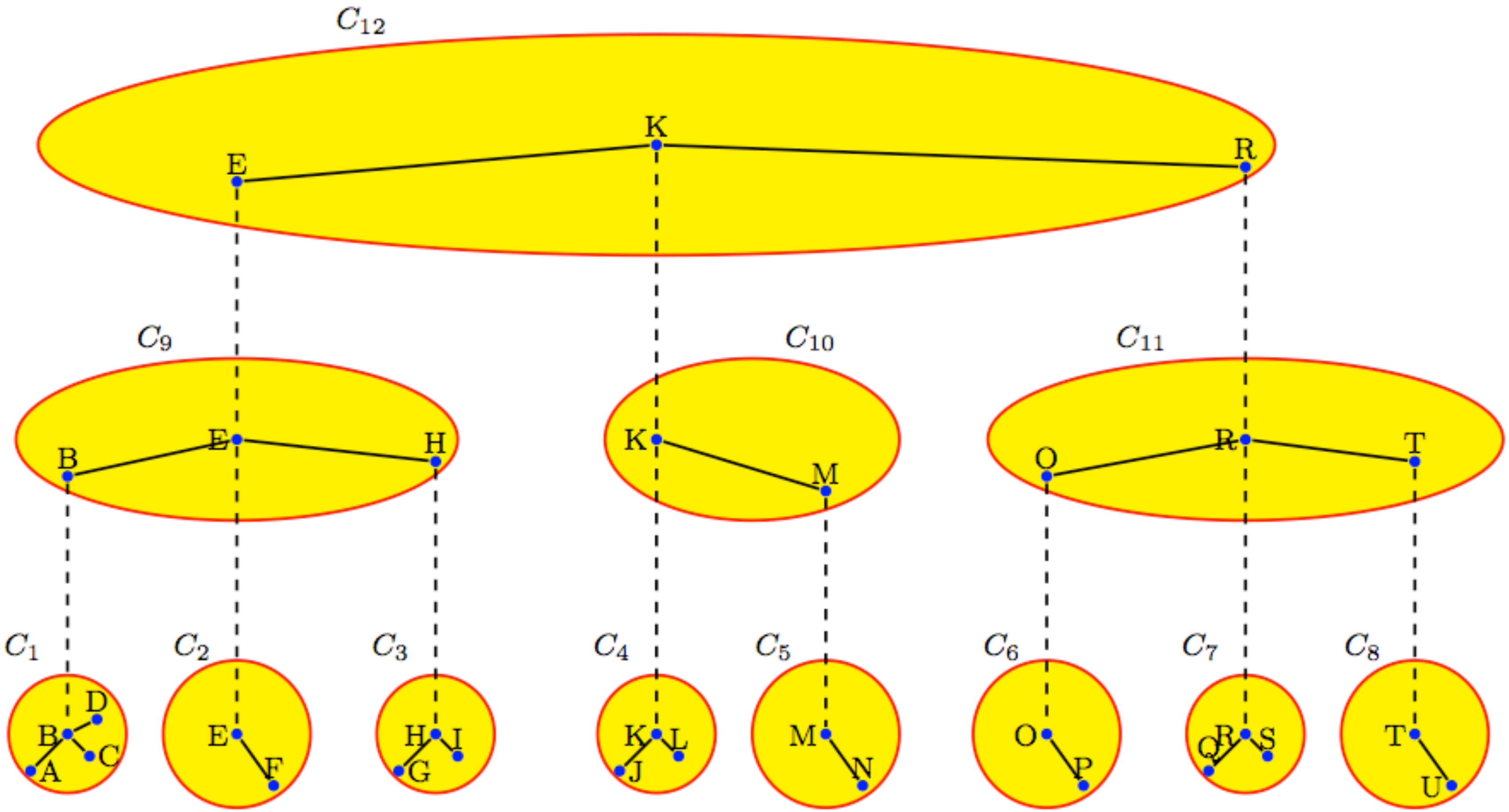
Modifications to the HCT (I)

- Covering radius
  - Original definition gives an approximation by defect
  - Consider all the elements belonging to the subtree
    - High computational cost
  - Approximation by excess

$$r_C = max(r_C(S_N), d(O_1, O_N) + r_C(S_1), ..., d(O_M, O_N) + r_C(S_M))$$

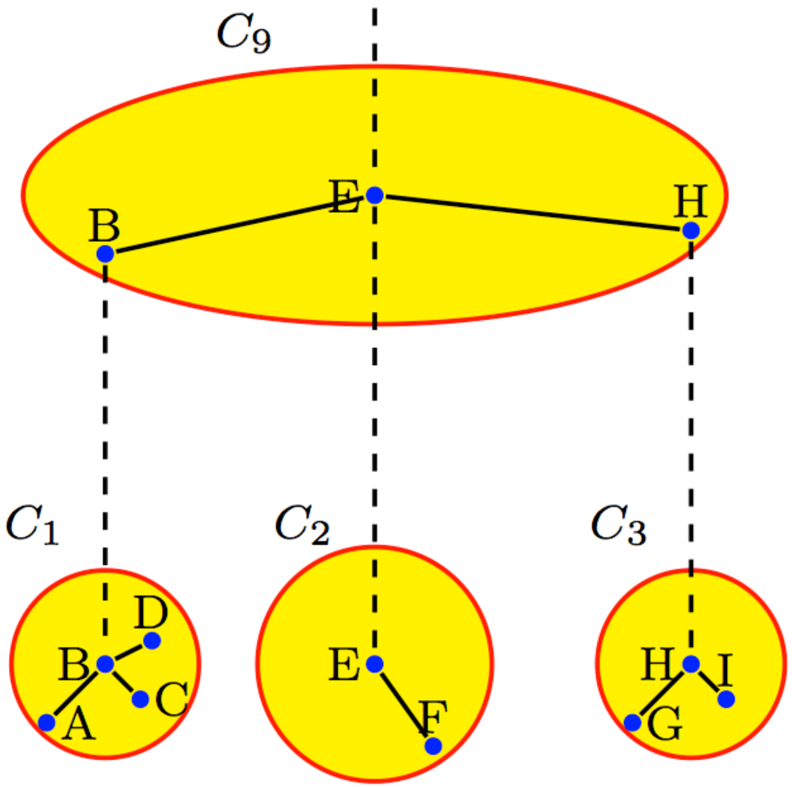
Modifications to the HCT (II)

- Covering radius



Modifications to the HCT (III)

- Covering radius



$$r_C(C_9) = \max \begin{cases} d(E,B)+r_C(C_1) \\ r_C(C_2) \\ d(E,H)+r_C(C_3) \end{cases}$$

Modifications to the HCT (III)

- HCT construction
  - Preemptive Cell Search over all the levels
  - A method for updating the covering radius
    - To reduce the searching time
    - It can be performed after the HCT construction or periodically

Modifications to the HCT (IV)

- Searching techniques
  - PQ fails in solving the KNN problem efficiently
  - New searching techniques
    - Most Similar Nucleus
    - Preemptive Cell Search
    - Hybrid
  - Number of cells to be considered
    - Minimum number of cells
    - Cells hosting $2 \cdot K$ elements
    - Cellular structure is not kept

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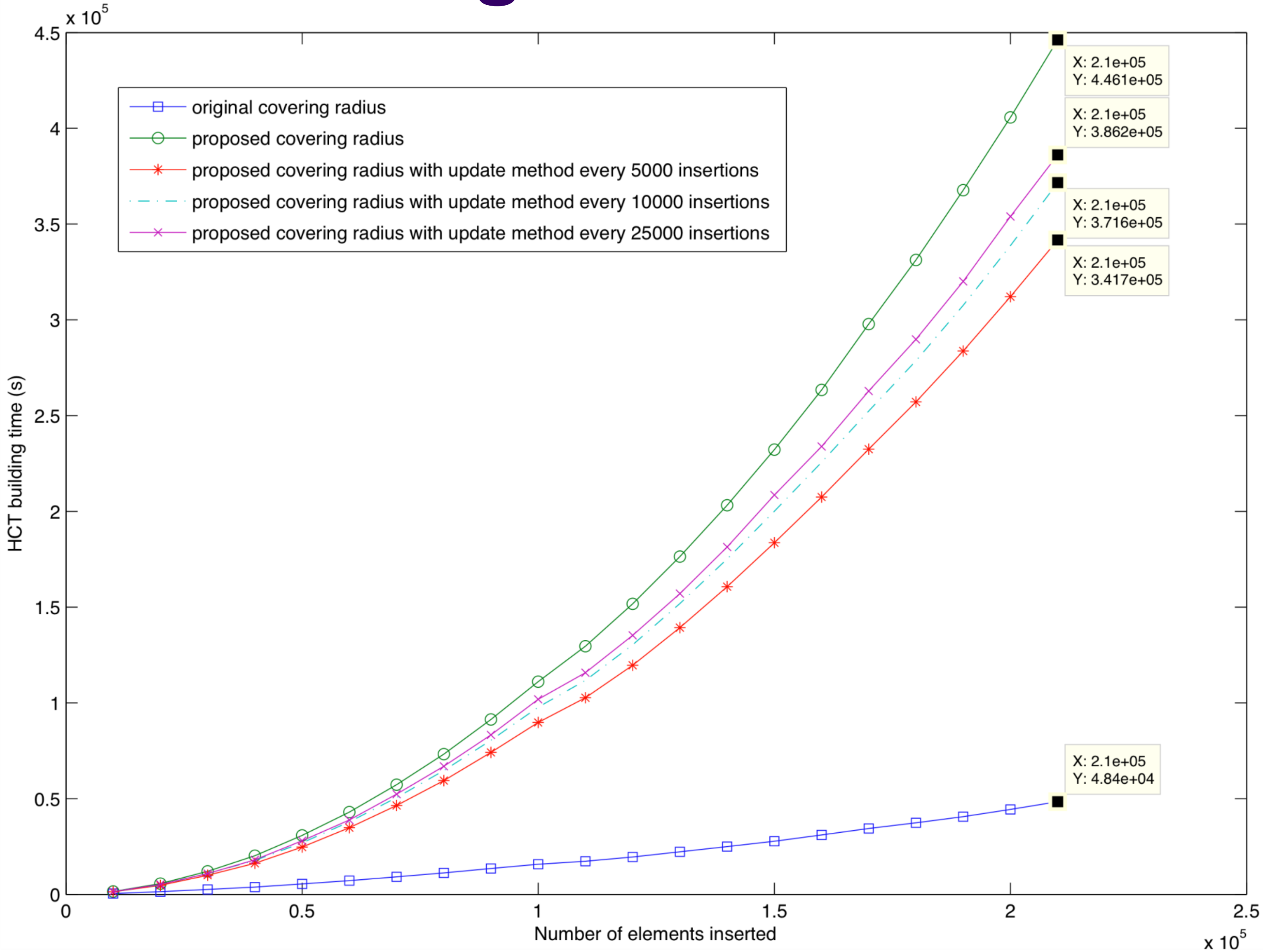
Experimental results

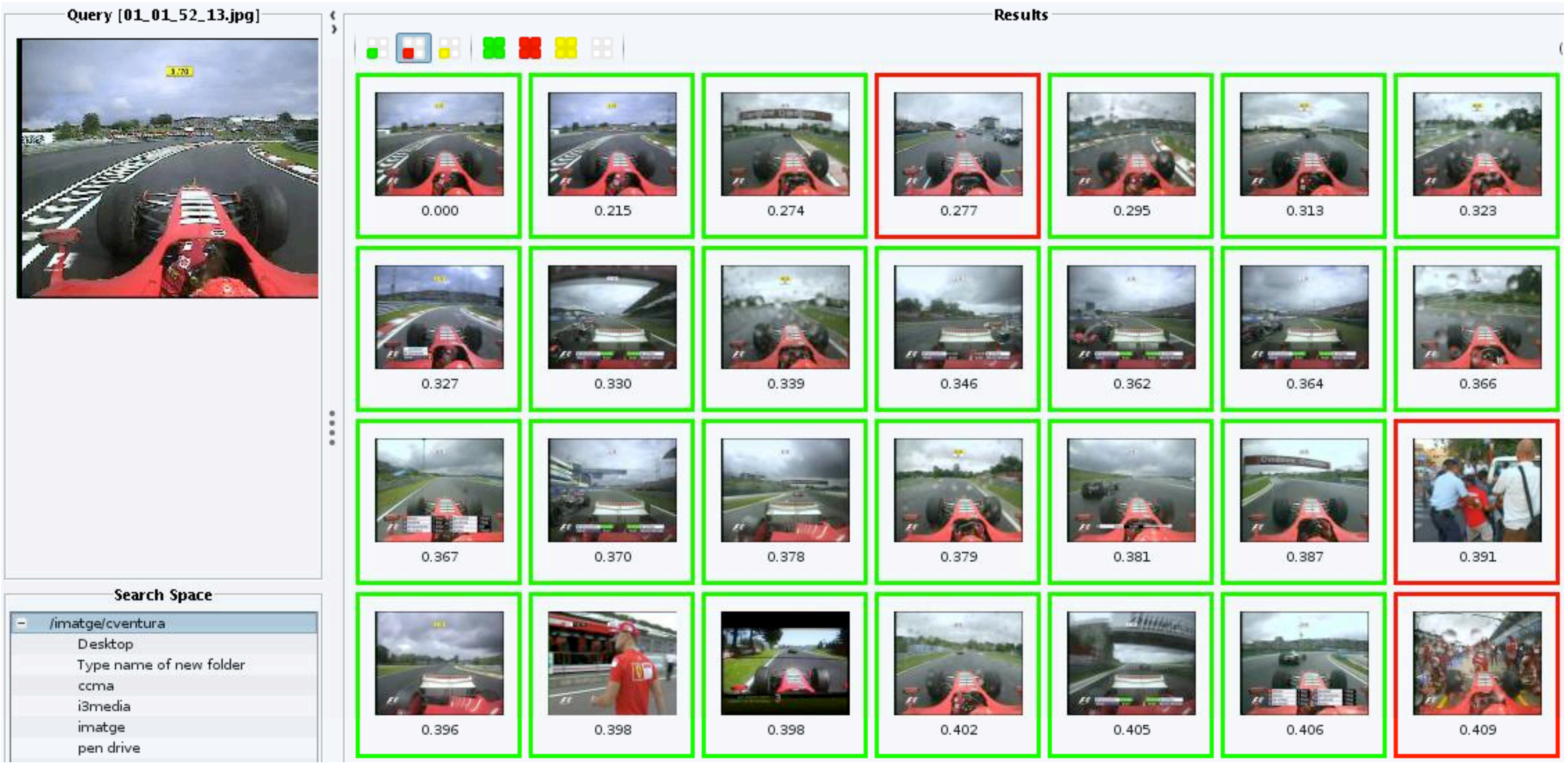
- CCMA image database of 216,317 elements
- HCT building evaluation
  - Construction time
- Retrieval system evaluation
  - Retrieval time
  - Elements retrieved

HCT building evaluation



Retrieval system evaluation (I)

Retrieval sytem evaluation (V)



Retrieval system evaluation (VI)

Retrieval system evaluation (II)

- Evaluation with respect to exhaustive search
  - Mean Competitive Recall
    - Elements in common
  - Mean Normalized Aggregate Goodness

$$NAG(k, q, A) = \frac{W(k, q, E) - \sum_{p \in A(k,q,E)} d(p, q)}{W(k, q, E) - \sum_{p \in GT(k,q,E)} d(p, q)}$$

  - Kendall distance
    - Number of exchanges needed in a bubble sort
  - Query set of 1,082 images

Retrieval system evaluation (III)

- Preemptive Cell Search

	proposed covering radius		original covering radius	
	non updated	updated	non updated	updated
Mean retrieval time (s)	**1.2386**	**0.8319**	0.1058	**1.0095**
Variance retrieval time (s)	0.1886	0.1466	0.0057	0.1994
Retrieved queries (%)	**99.26**	**99.26**	49.26	**97.04**
$\overline{CR}$	**28.09**	**27.51**	12.35	**26.42**
NAG	0.9970	0.9967	0.9814	0.9965
Kendall	295.24	313.87	934.14	356.92

Retrieval system evaluation (IV)

- Searching techniques comparative

	MS-Nucleus	Hybrid (7 levels)	Hybrid (8 levels)	Hybrid (9 levels)	Preemptive	MS-Nucleus (20,000 el)
Mean retrieval time (s)	**0.0072**	0.2172	0.4144	0.6835	**0.8319**	1.3695
Variance retrieval time (s)	2.1e-05	0.0009	0.0093	0.0569	0.1466	0.0054
Retrieved queries (%)	**5.00**	37.99	57.95	84.20	**99.26**	31.61
$\overline{CR}$	**1.35**	9.83	14.22	20.81	**27.51**	12.33
NAG	0.9087	0.9727	0.9824	0.9917	0.9967	0.9776
Kendall	1530.93	1106.08	883.51	580.43	313.87	1025.71

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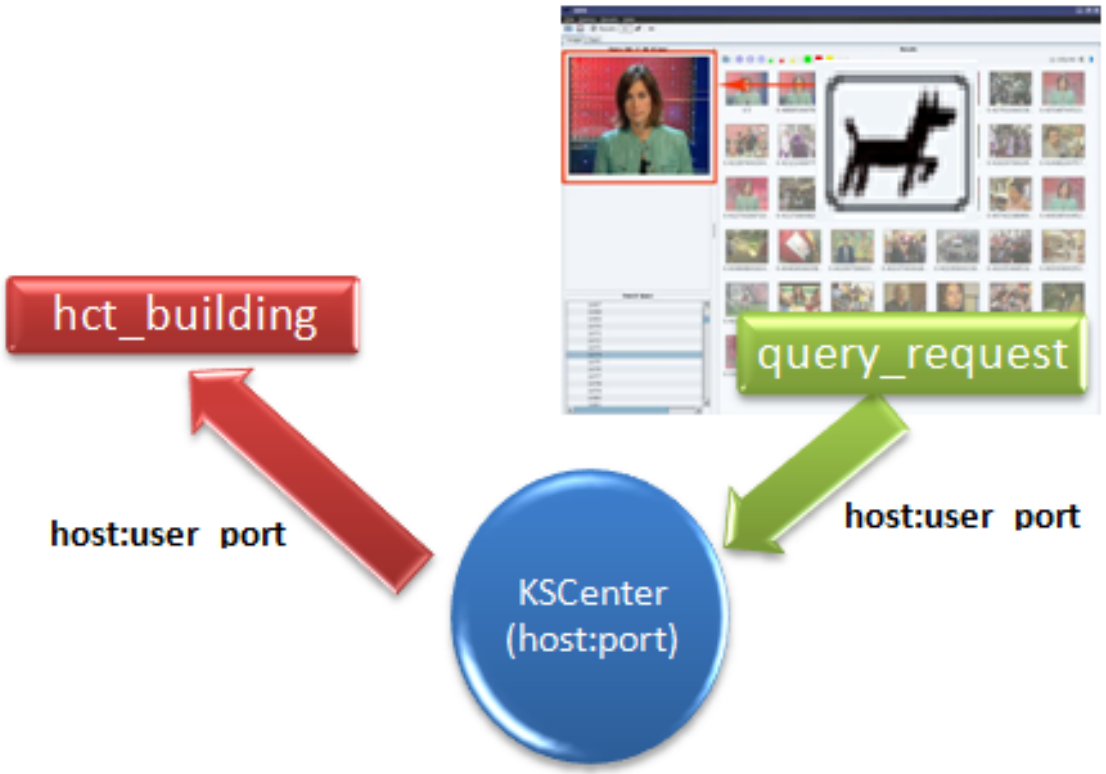
Implemented tools (I)

- database_indexing tool
  - Tool for indexing an image database
  - HCT is stored at disk
- hct_query tool
  - Tool for carrying out a search over an indexed database
  - HCT is read from disk and load at main memory

Implemented tools (II)

- A server/client architecture
  - Based on a messaging system: KSC



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Conclusions

- Hierarchical Cellular Tree implementation
  - To improve the retrieval times
  - Generic implementation for any kind of data
  - Modifications proposed
- HCT evaluation
  - Measures extracted from literature
- Preemptive Cell Search technique gives the best performance
  - It is essential not to use an underestimated value for the covering radius

Future work lines

- Very large databases
  - Not using only main memory
- Region-based CBIR system
  - Each image can be represented by a set of regions
- Browser application based on HCT
  - Take advantage of the hierarchical structure
  - Alternative way to retrieve elements

Thanks for your attention