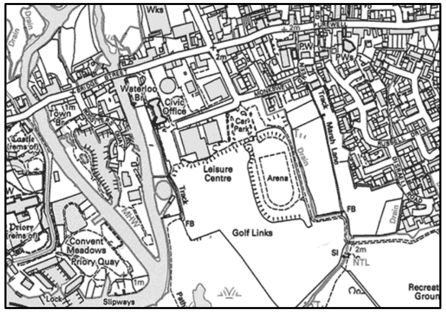

Use of GIS for Planning Visual Surveillance – An Analogy to Maximal Coverage Problem

Sanjay Rana

TOPICS

1. Background: Characteristics and Role of GIS
2. Visibility Analysis in urban open spaces
3. Automated Observer Placement Algorithms in GIS
4. Examples
5. Conclusions and Future Directions

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November 16 2005

Britain

The Times November 15, 2005

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BY STEWART TENDLER, CRIME CORRESPONDENT

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By David Millward, Transport Correspondent
(Filed: 15/11/2005)

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Smart CCTV for the tubes?

Automation, that's what we need

By Lucy Sherriff
Published Tuesday 15th November 2005 15:11 GMT

Transport officials are looking into a so-called Smart-CCTV system that would automati[...] managers of tubes and trains to left packages or odd behaviour.

Trials of this kind of technology have so far proven unsuccessful. Trials of so-called sm[...]

1. Background

- The use of visual surveillance has dramatically increased in recent years, as demands arose for monitoring,
  - Suspicious behaviour in public spaces,
  - Traffic,
  - Employees in work places,
  - etc. etc.
- 1023 million GBP spent during 2004 on sales and rental of CCTV (source: MBD Press, 2005).

2005

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Surveillance & Situational Awareness

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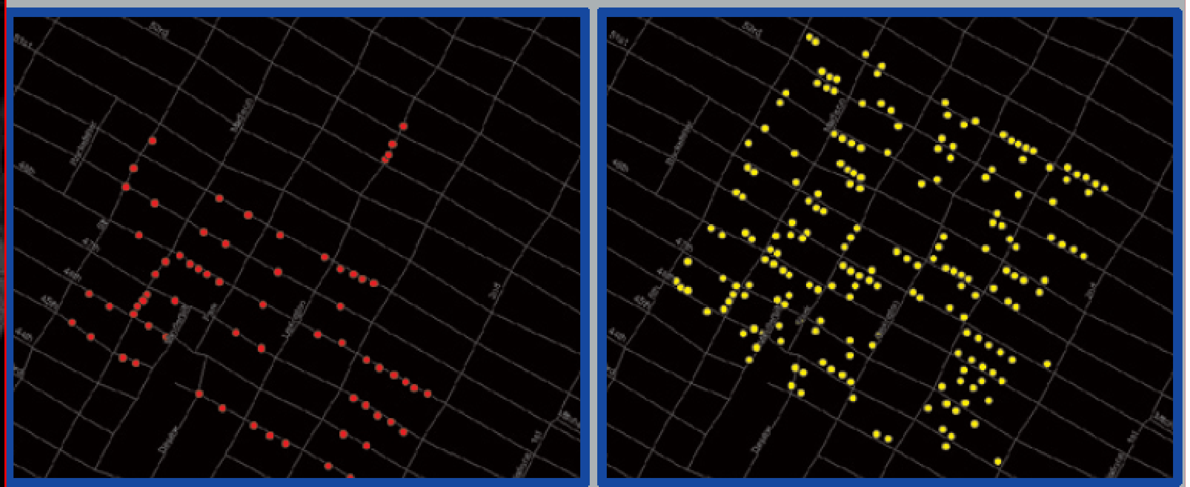


November 1998
56 Cameras
New York Civil Liberties Union

January 2002
197 Cameras
Surveillance Camera Players

CCTV CAMERAS IN MANHATTAN

1.1 Two types of visual surveillance:

- Active or Artificial Visual Surveillance:
  - Direct and intrusive remote monitoring via devices such as CCTV or human observers.
  - Potentially more effective but costly.
- Passive or Natural Visual Surveillance
  - Design of open spaces so as to ensure that occupants can self-regulate themselves.
  - Cheap, long lasting but involves a risk.

1.1.1 Artificial Visual Surveillance

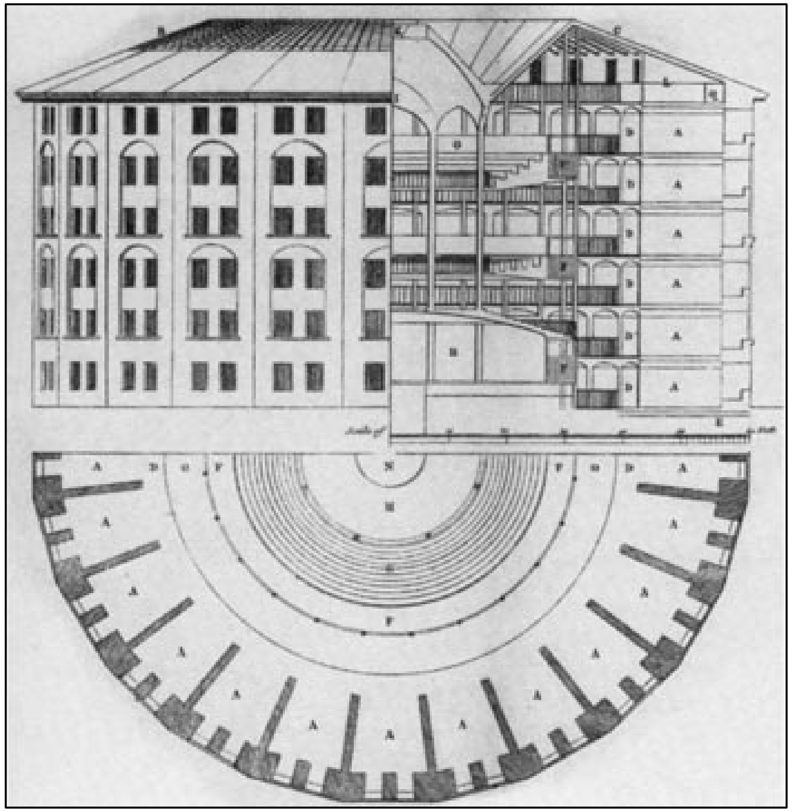
- The aim is to ensure complete/maximum visual coverage of an open space.
- It involves an iterative, manual and gut-feel process of trying various CCTV layouts until a satisfactory solution has been found.
- Traditionally done by architects, security consultants and urban planners using CAD software.

EXAMPLE OF ARTIFICIAL VISUAL SURVEILLANCE: IDENITIFICATION OF THE FOUR SUSPECTS IN LONDON TRANSPORT NETWORK BOMBINGS (JULY, 2005)

1.1.2 Natural Visual Surveillance

- The aim is to create the perception of being observed or safety by suitable architectural design of an open space:
  - Occupants can see other occupants and entry/exist points in space, so that they can self-regulate themselves, e.g., in public spaces,
  - Occupants always feel being watched by an invisible observer.
- Measures include removal of blind spots, dark alleys, installing one-way screens (Venetian blinds) etc.

FAMOUS EXAMPLE OF NATURAL VISUAL SURVEILLANCE: THE PANOPTICON PRISON DESIGN BY JEREMY BENTHAM



- A central guard tower, surrounded by prison cells but the prisoners can neither see each other nor the prison guards therefore creating the perception of being under constant invisible observation.

- Examples include Twin Towers Correctional Facility (LA) and Pentonville Prison (England).

- Aim of the talk is to demonstrate:
  - GIS-based automated observer placement algorithms that ensure complete visual coverage (artificial visual surveillance),
  - Measures to characterise the quality of visibility in open spaces (natural visual surveillance).

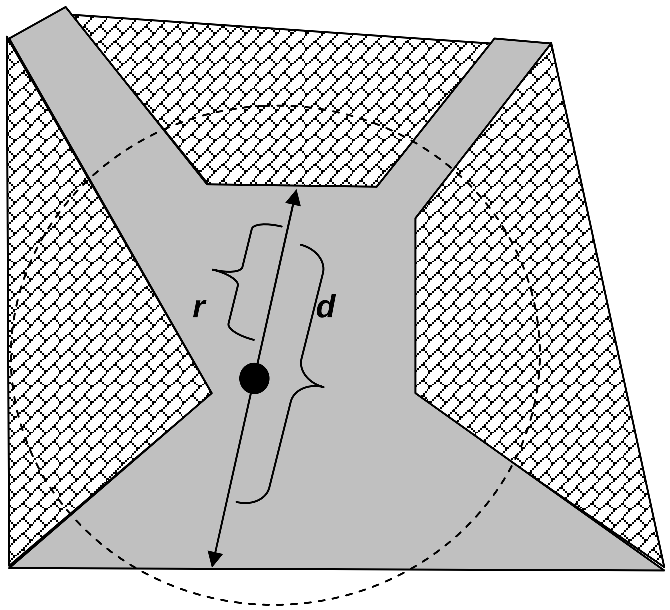
2. Visibility Analysis in urban open spaces

- Intellectually challenging and multi-purpose with applications including accessibility evaluation, pedestrian behaviour modelling, surveillance, aesthetics etc.
- Architecture surrounding urban open spaces is geometrically quite complex for analysis.
- Void or open space between architecture is a sort of template (or mirror image) and can be easily characterised.

2.1 Isovist

- Concept proposed by Michael Benedikt (1979).
- It is the space visible from a location, basically similar to the idea of viewshed in terrain analysis and visibility polygon in computer graphics.
- Most commonly derived using 2D building plans and street networks. Hence, unlike viewshed in terrains, isovists do not have gaps in visibility.
- The shape of an isovist can be described in 2D morphological measures.

2.1.1 Some isovist shape descriptors:



Area: Amount of visible space

Radial (r) and Diametric (d) length: Length of line of sight from the viewpoint

Circularity: Level of resemblance of the isovist polygon to a circle

- Perception of safety and well-being in an open space can be correlated to the visibility properties of the open space for instance, poorly lit (e.g., by natural light) areas generate fear,

- People follow cues (e.g., long corridors) in the space while exploring open spaces.

Greene, M., and Greene, R., 2004, Urban safety in residential areas, Space Syntax Conference.

3. Automated Observer Placement Algorithms in GIS

- Costs of installation and maintenance, and coverage of CCTV cameras need to be addressed.

- The problem of ensuring maximum visual coverage with a minimum number of CCTV/observers is <u>broadly</u> similar to *Location-Allocation*, *Chinese Postman/Travelling Salesman* problems in GIS, and <u>closely</u> similar to the *Art Gallery Problem* in Computer Science.

Why use a GIS?

- Planning of visual surveillance is essentially a geospatial problem, involving cartographic maps of street networks and building plans,
- Determination of visual accessibility is crucial to visual surveillance. Vast GIS literature exists on viewshed in terrain and visibility analysis in urban environments,
- Topological analysis of physical accessibility in open spaces is essential for monitoring navigation. Topology remains the most basic property of objects in spatial analysis and thus most GIS handle topology very well.
- Despite the obvious potentials above, there are no in-built functions in most GIS for something even basic as visibility computation in urban environments (mostly 2D building plans).

3.1 Art Gallery Problem (AGP)

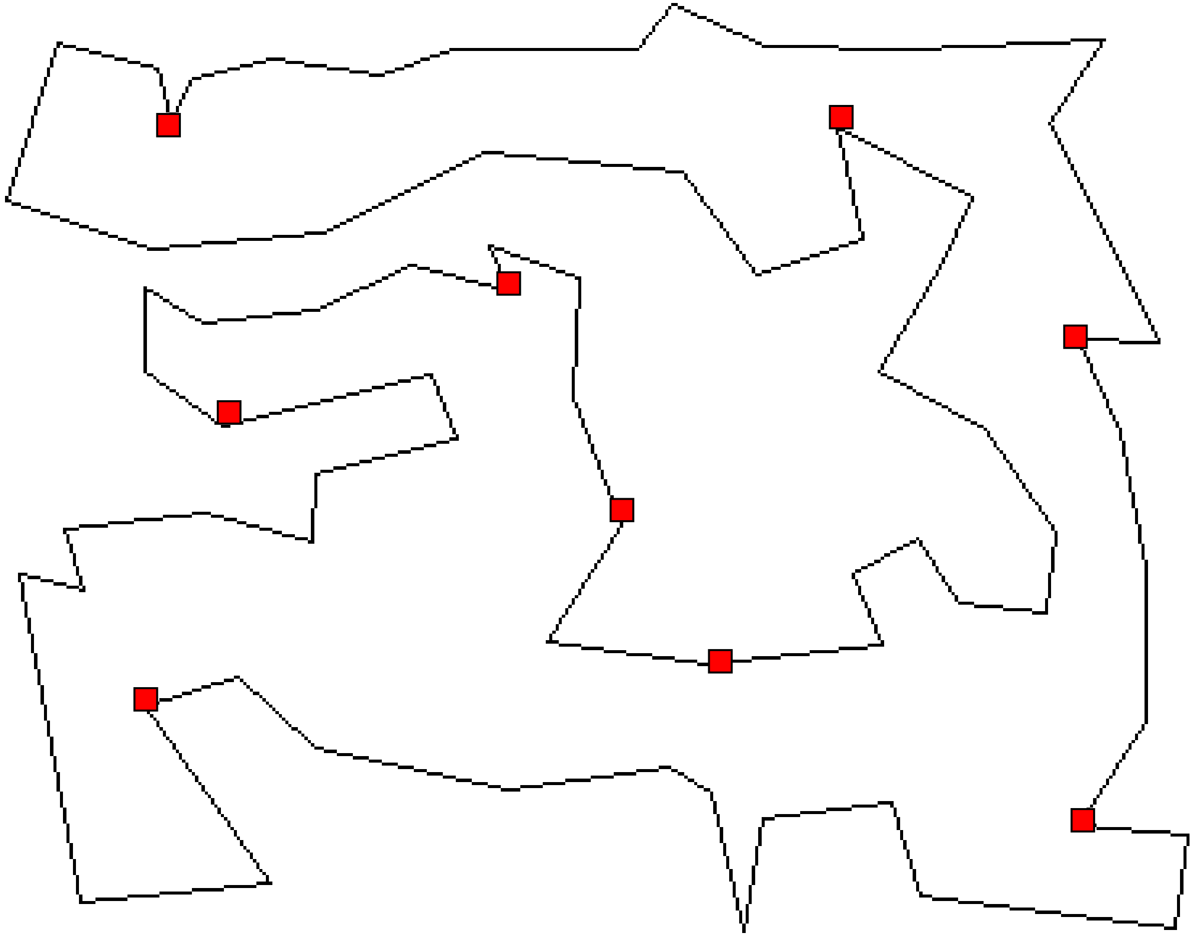
- Proposed by Victor Klee in 1973.
- What’s the minimum number of guards necessary to provide complete visual coverage of an art gallery?
- Solution of the AGP is going to be relevant for an affordable and effective CCTV network.
- However, there are no robust algorithms that guarantee a general purpose solution.
- The problem is NP-hard. Thus, it is analytically and computationally non-trivial.

- Most existing algorithms assume a certain topology of the art gallery e.g., rectilinear, convex, etc.
- A well known formula to solve the AGP is,
  - For a gallery with *n* walls and *h* holes,

$$\left\lfloor \frac{n+h}{3} \right\rfloor$$

  number of guards are sufficient to provide complete visual coverage,
  - This solution doesn't guarantee the minimum number in all shapes but definitely yields a number enough for complete visual coverage e.g.,

HOW MANY GUARDS ARE SUFFICIENT TO COVER THE GALLERY ?



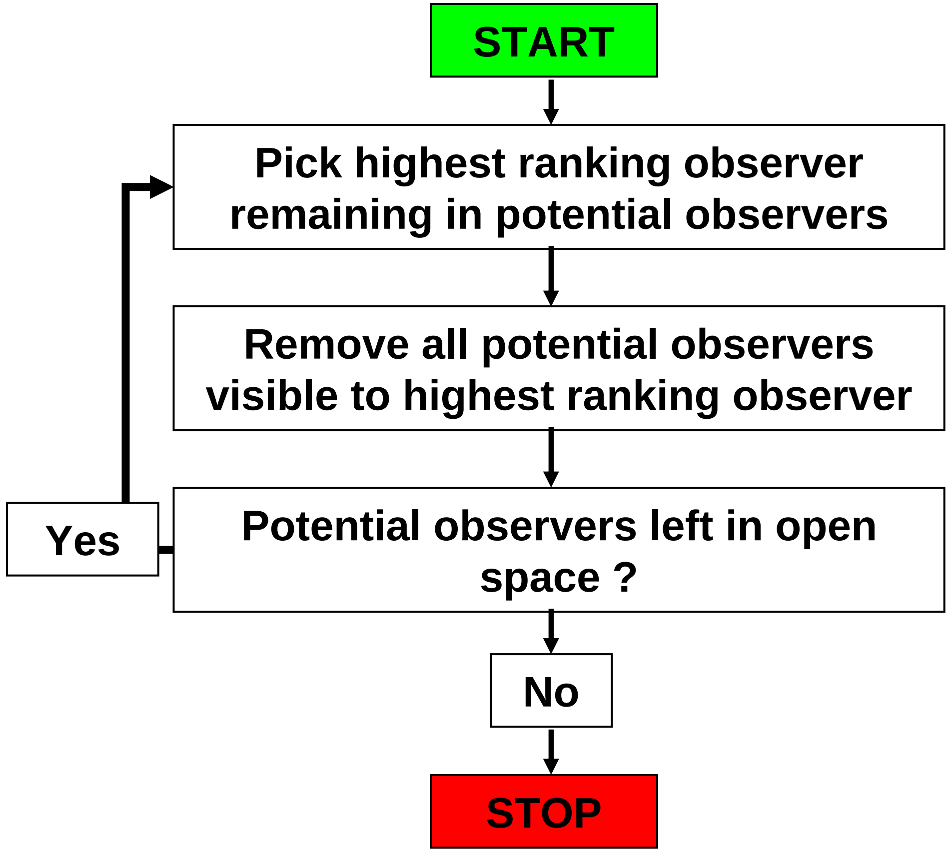
71 WALLS

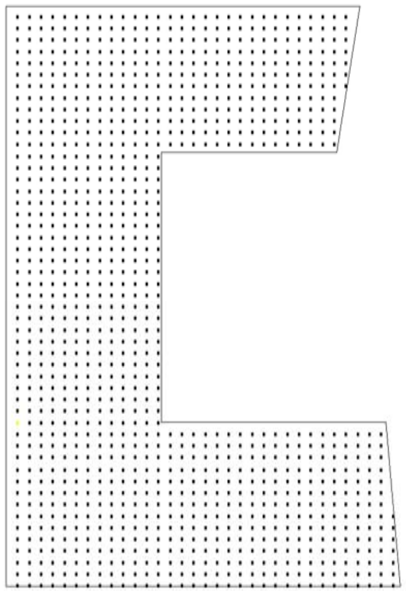
(n+h)/3 = 23?
But really need:
9

3.1.1 Rank and Overlap Elimination (*ROPE*)

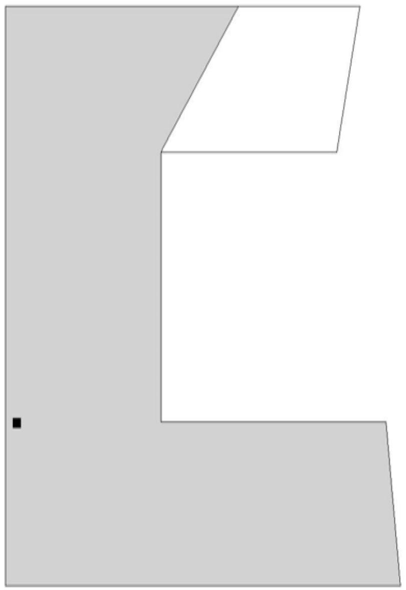
- It is essentially a greedy-search method.
- The open space is discretised with a dense mesh of potential observers.
  - Each observer is assigned a rank based on the number of other observers seen by it. Higher rank means higher visibility.
  - Starting with the highest ranking observer, an iterative process selects the optimal observers:

ROPE SELECTION PROCESS FLOWCHART

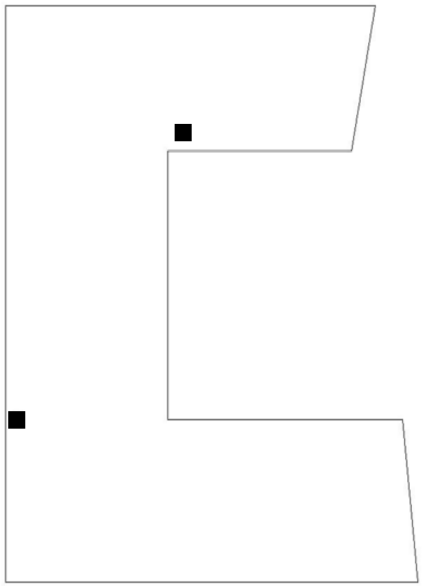




Dense Mesh of Potential Observers

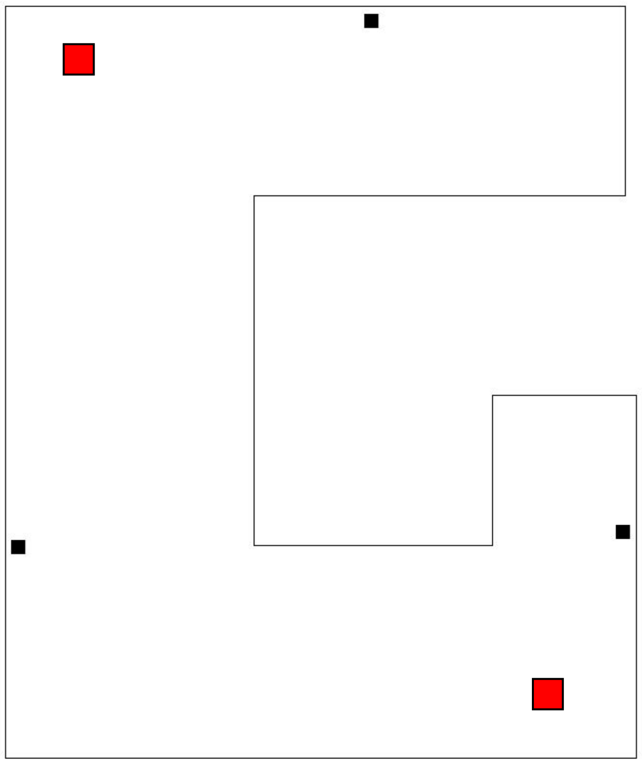


Isovist of the highest ranking observer



Two optimal observers

ROPE technique doesn't guarantee the minimum number of observers.



- Optimal Observers
- ROPE Observers

But it's not worse than the (n+h)/3 solution:

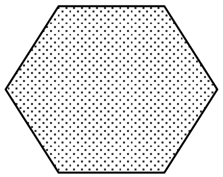
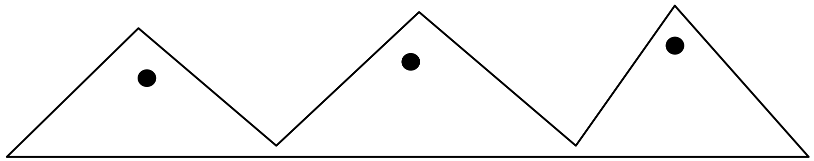
(10 walls + 0 holes) / 3 = 3 observers

3.1.2 Stochastical *ROPE (S-ROPE)*

- Output of greedy-search depends upon initial solution,
- Similarly, *ROPE* output could be improved by starting the overlap elimination with randomly chosen observers and choose the solution with least number of optimal observers.
- An exhaustive approach would be to start once with each potential observer.

3.1.3 Run-time Complexity

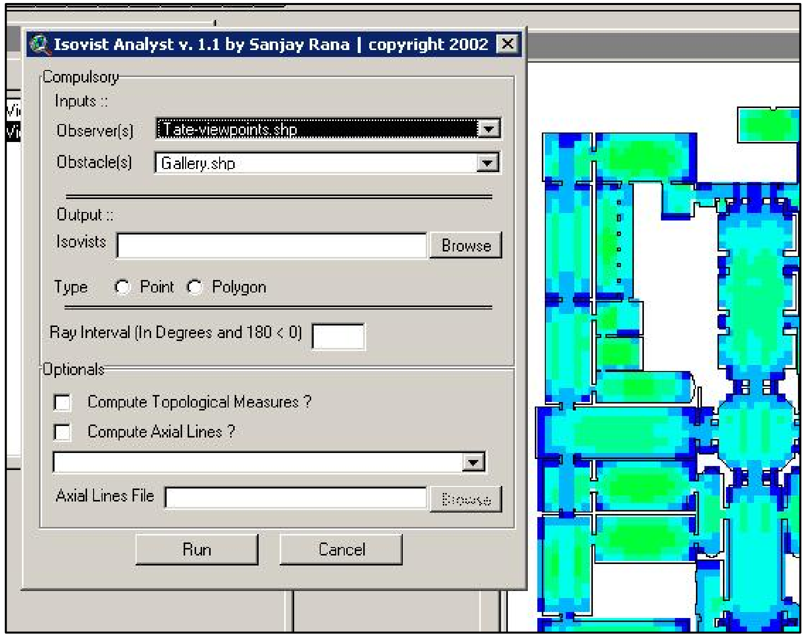
- Depends upon the amount of overlap.

Range of Mutual Overlap	 **Complete**	 **Nil**
ROPE	$O(1)$	$O(n)$
S-ROPE	$O(1)$	$O(n^2)$

3.1.4 Isovist Analyst extension for ArcView

- Allows computation of isovist and shape measures,
- Open space can be of arbitrary topology (e.g., with/out holes) and geometry (e.g., lines, polygons).
- Integration of urban visibility analyses in GIS.
- Available free for non-commercial, non-profitable, and personal use.

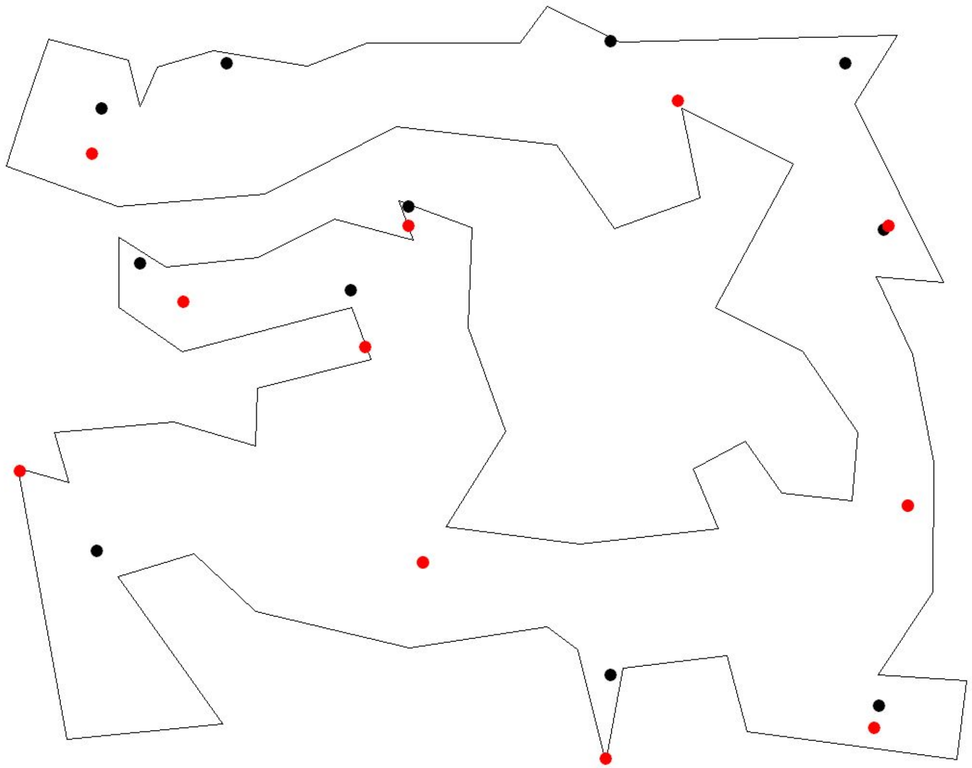
Software Demonstration



4. Examples

1. **Arbitrary closed polygon (complicated shape)**
2. **Tate Britain Gallery (an indoor open space)**
3. **Aldwych area (an outdoor street network)**

4.1 Arbitrary Polygon – Visual Coverage



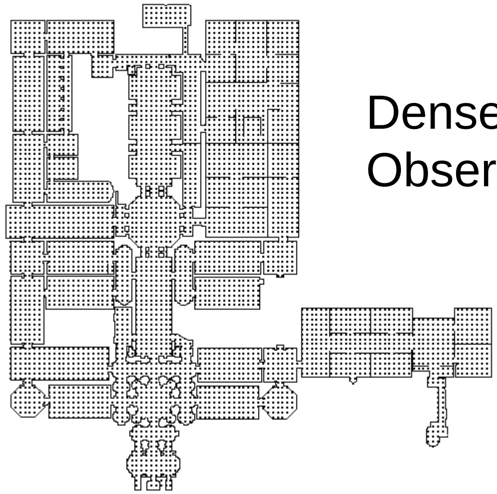
● ROPE observers (13)

● S-ROPE observers (11) based on 5177 initial solutions

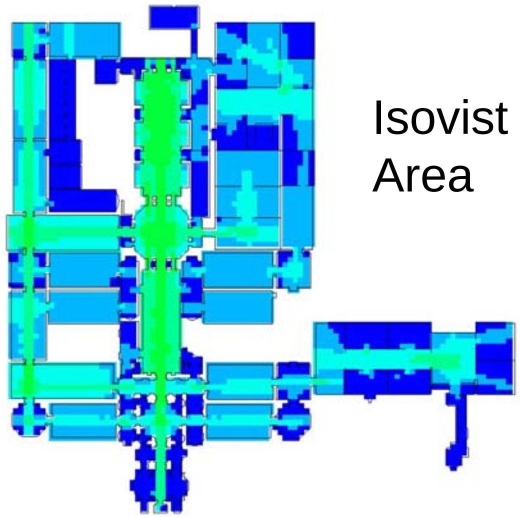
(n+h) / 3 solution:

71 walls = 23 observers

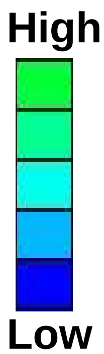
4.2 Tate Britain Gallery - Shape

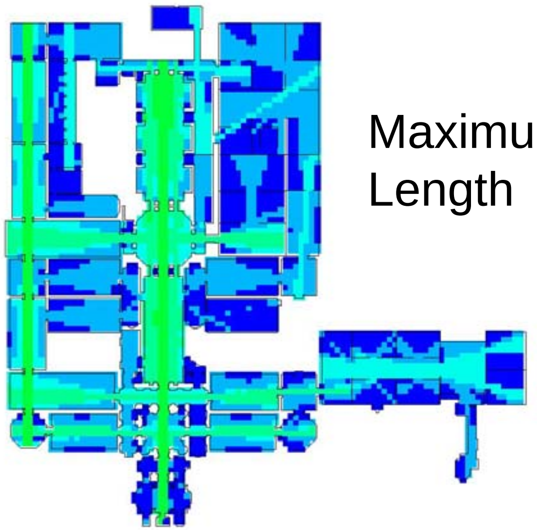


Dense Mesh of 4298 Observers

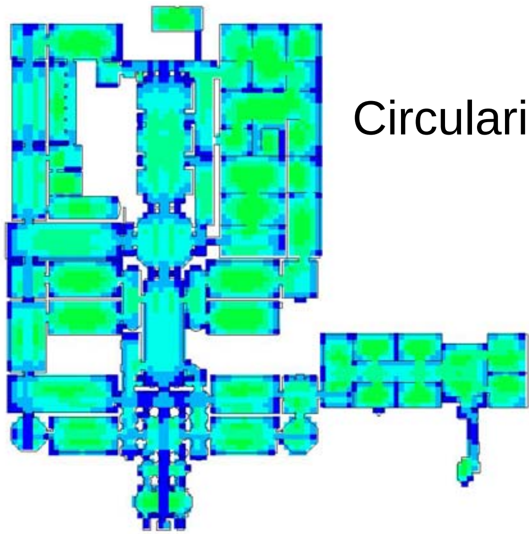


Isovist Area



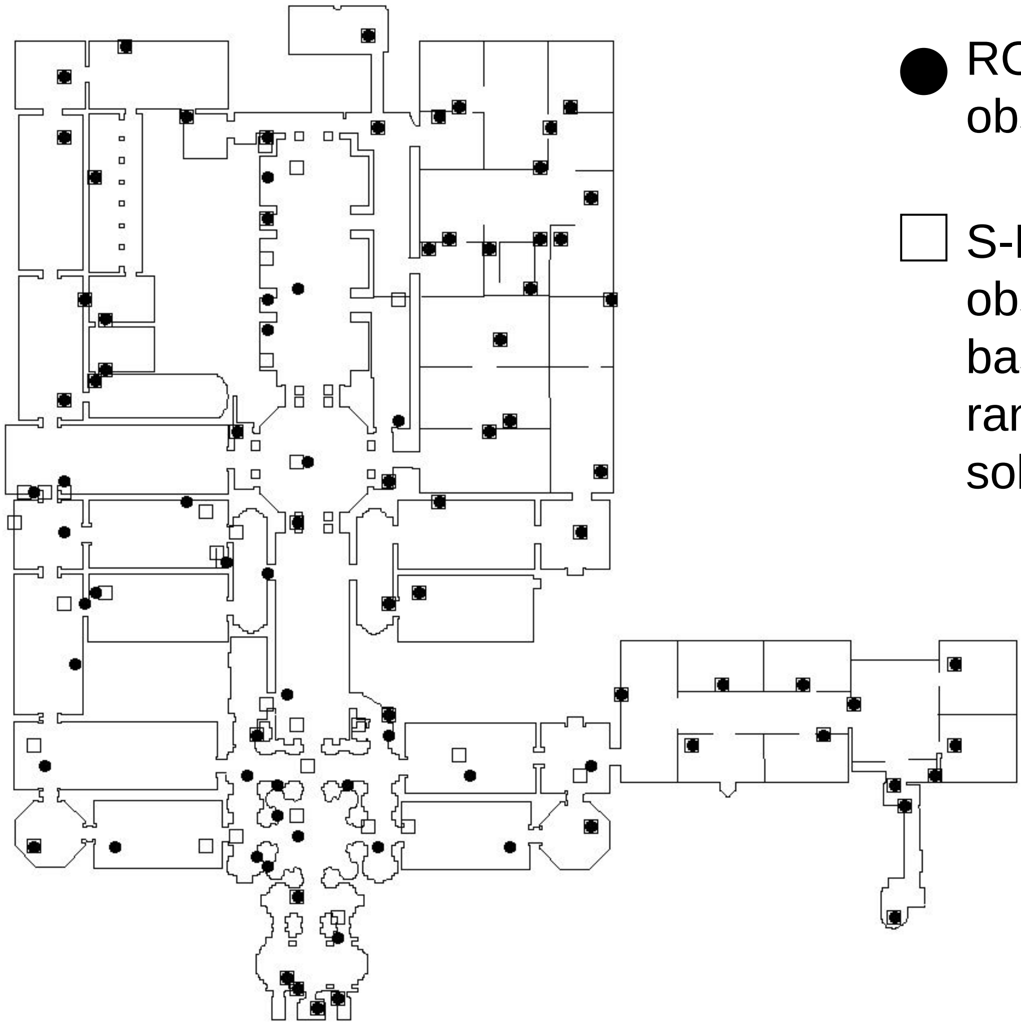


Maximum Diametric Length



Circularity

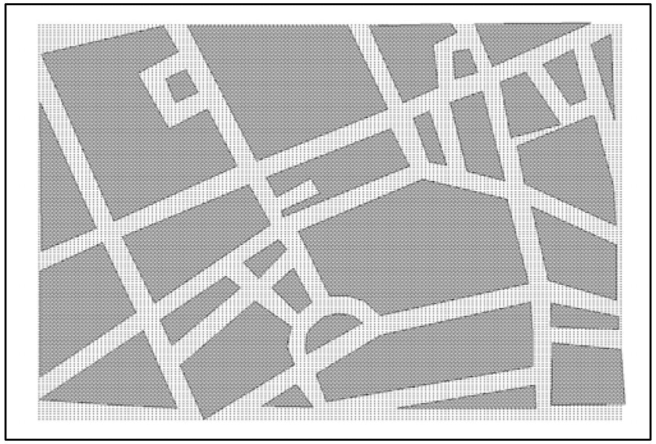
4.1 Tate Britain Gallery – Visual Coverage



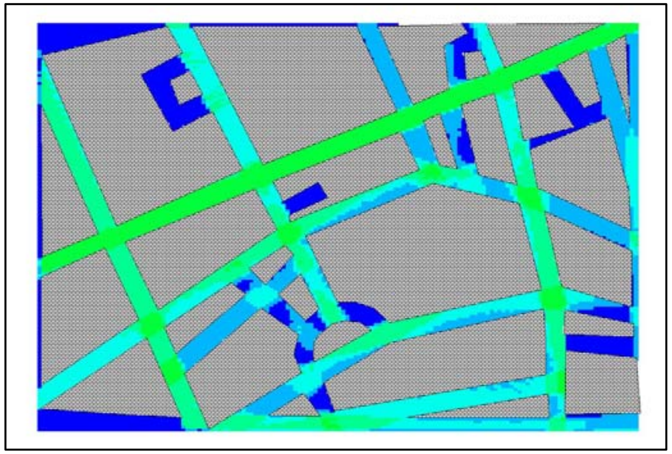
● ROPE observers (90)

□ S-ROPE observers (86) based on 100 random initial solutions

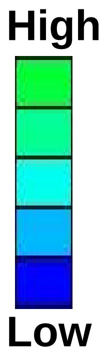
4.3 Aldwych Street Network - Shape



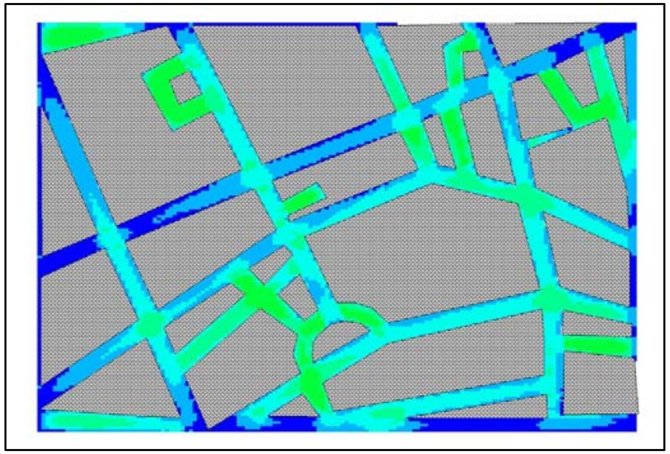
Dense Mesh of 8427 Observers



Isovist Area

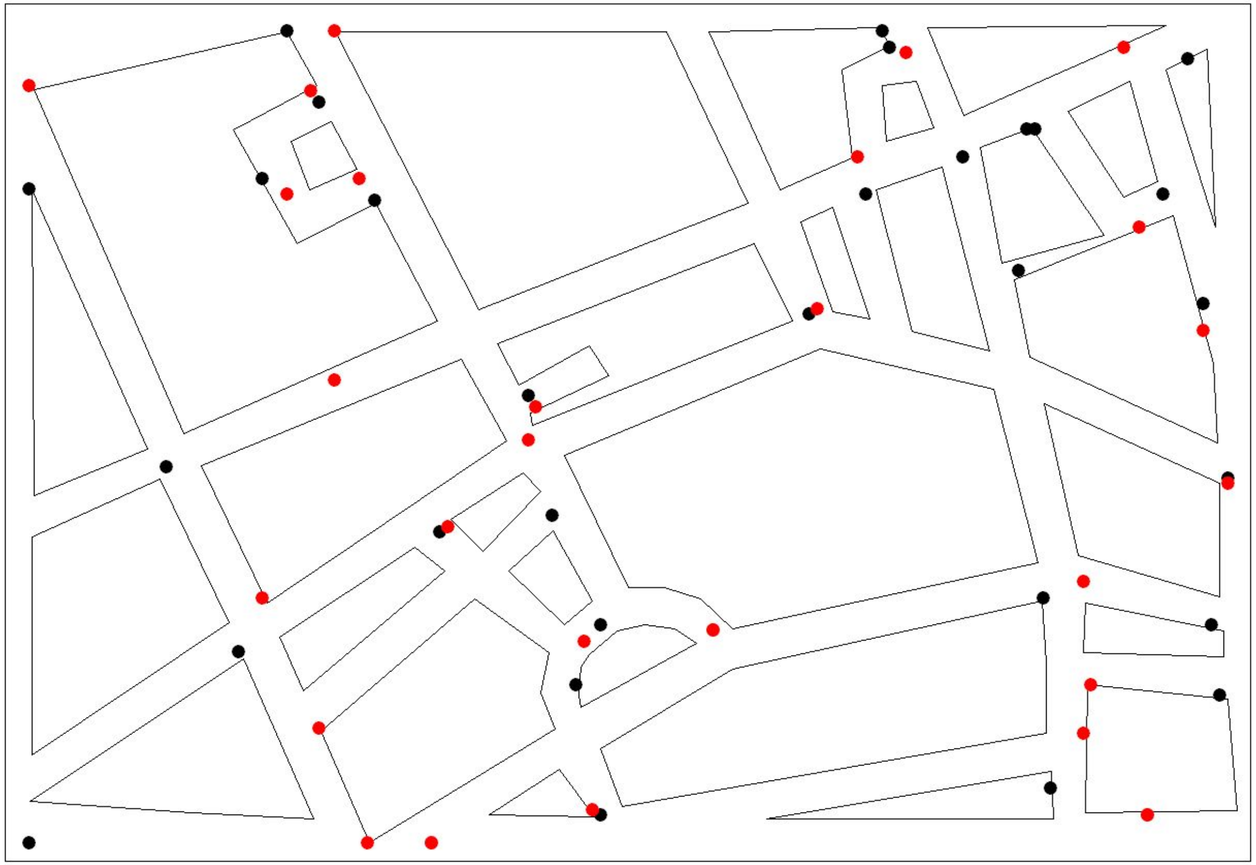


Maximum Diametric Length



Circularity

4.2 Aldwych Street Network – Visual Coverage



ROPE observers (33)

S-ROPE observers (27) based on 100 random initial solutions

5. Conclusions and Future Directions

5.1 This work demonstrates:

- Visual Surveillance has become a necessary aspect of modern society,
- Planning of Visual Surveillance is essentially a geospatial exercise.
- Most GISs do not provide in-built functions for planning visual surveillance.
- Automated algorithms for evaluating the structure of open spaces and planning visual coverage, in relation to planning visual surveillance can be easily developed in a GIS.

5.2 Future Directions

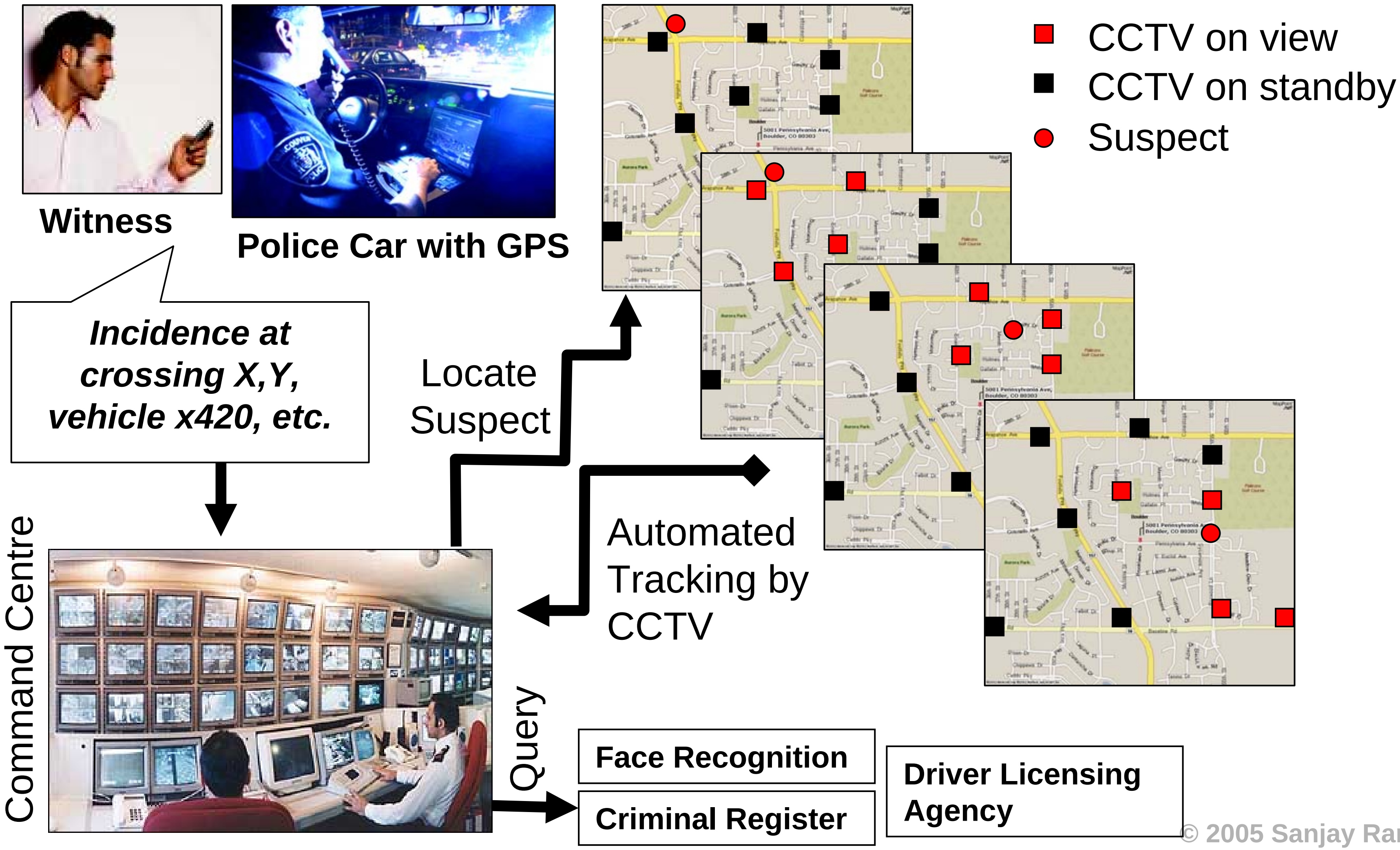
5.2.1 What's the Big Picture??

URBAN VISUAL

SURVEILLANCE SYSTEM

Incorporating real-time distributed GeoSpatial Intelligence in CCTV

"Sci-Fi" about the operation of UVSS



5.2.2 Accessibility related applications:

- Ensuring relevant signs (exit, no smoking, fire points) are always in view.
- Planning the stops in a guard’s patrol (pers. comm. James Paskins).

Acknowledgements:

- Discussions:
  - Ed Pegg Jr., Andy Chow, Puff Addison, and James Paskins.
- Software:
  - Yiorgos Chrysanthou for the visibility computation.
- Images:
  - www.eprison.us for CCTV and command centre images.
  - www.nhslothian.scotland.nhs.uk for the crowd image.
  - Ordnance Survey (UK) for Landplan map image (crown copyright).
  - www. isee.com for the CCTV coverage of Manhattan image.
  - Conroy and Dalton (1999) for the Tate Gallery outline.
  - Ed Pegg Jr. for the arbitrary polygon.
  - www.mda.ca for the police vehicle image.
  - www.imcb.org.uk for the man on the phone image.
  - uucboulder.org for the city map.
- **ESRI** and **UCL** Graduate School for the expenses support in relation to the conference presentation.