Validation and Verification Using Spatial Logic Framework for Building Layouts

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Agenda

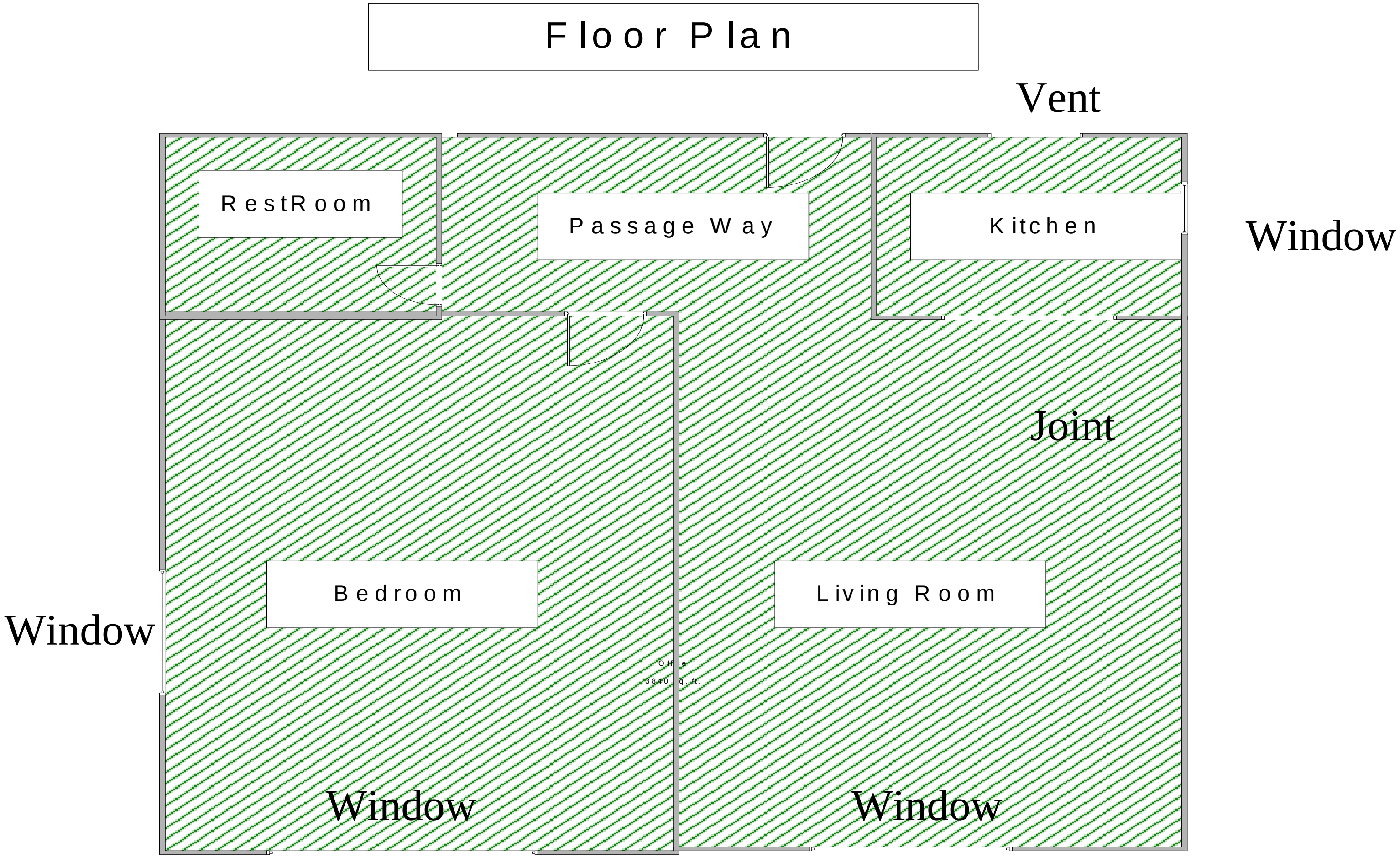
- Background
  - Project Description
  - Floor Plan
  - Goals
  - System Requirements
  - System Structure
- Spatial Logic
  - Overview
  - Application to Building Layouts
- Conclusion
- Software Used
- References

Background

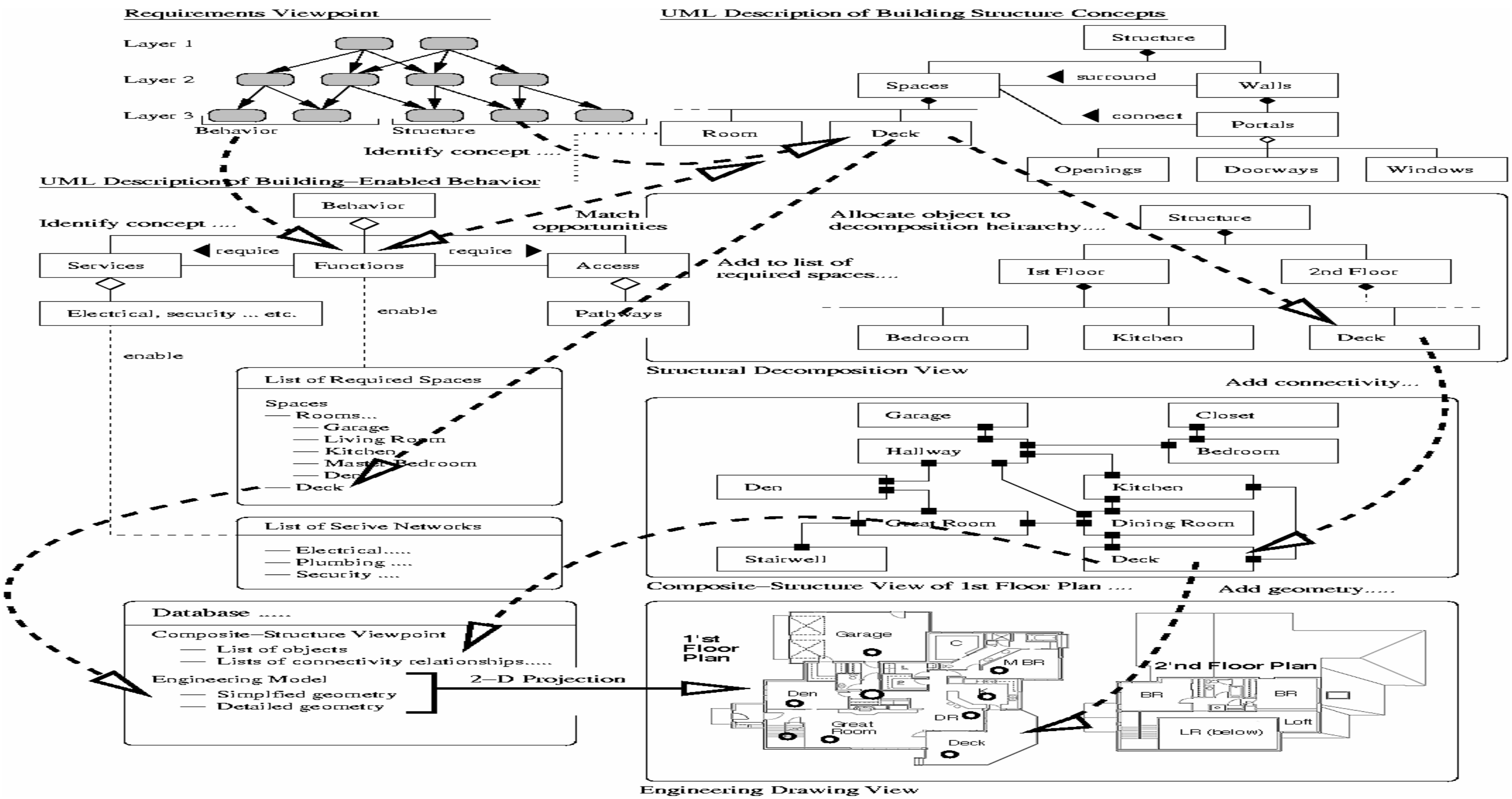
Background – Project Description

- Defined and categorized the design requirements of a building from an architectural view point
- Prepared the system structure (Class Diagram) at a higher level of abstraction
- Defined Validation Parameters
  - To allow the architect to check potential building designs against the specification
    - Quickly
    - Easily
    - In early phases of the design

Background - Floor Plan



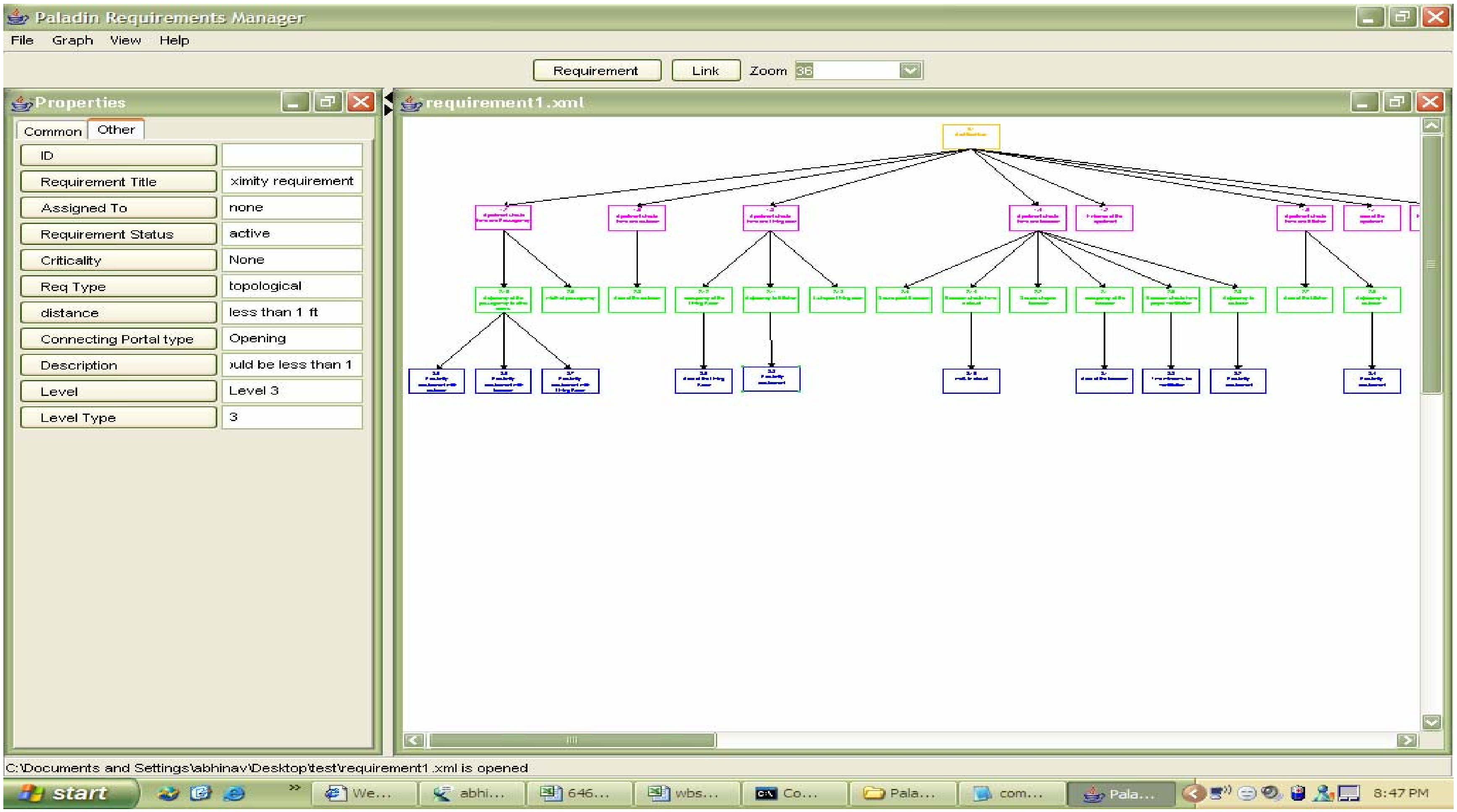
Background – Goals – Cont'd



Background—System Requirements

- Architectural requirements of one bedroom apartment can be broadly categorized as
  - Apartment Level:
    1. Area of the apartment should be at least 10000 sq units.
    2. The apartment should have 1 bedroom, 1 living room, 1 kitchen, 1 restroom and one passageway.
    3. The apartment should have easy access to exit in case of fire.
  - Room Level:
    4. Occupancy of the bedroom should be two.
    5. Bedroom should be adjacent to the restroom.
    6. Proximity strength between restroom and bedroom is 1.
    7. Bedroom should have air tight and sound proof doors.
    8. Orientation of the bedroom should be towards the west.

Background—System Requirements



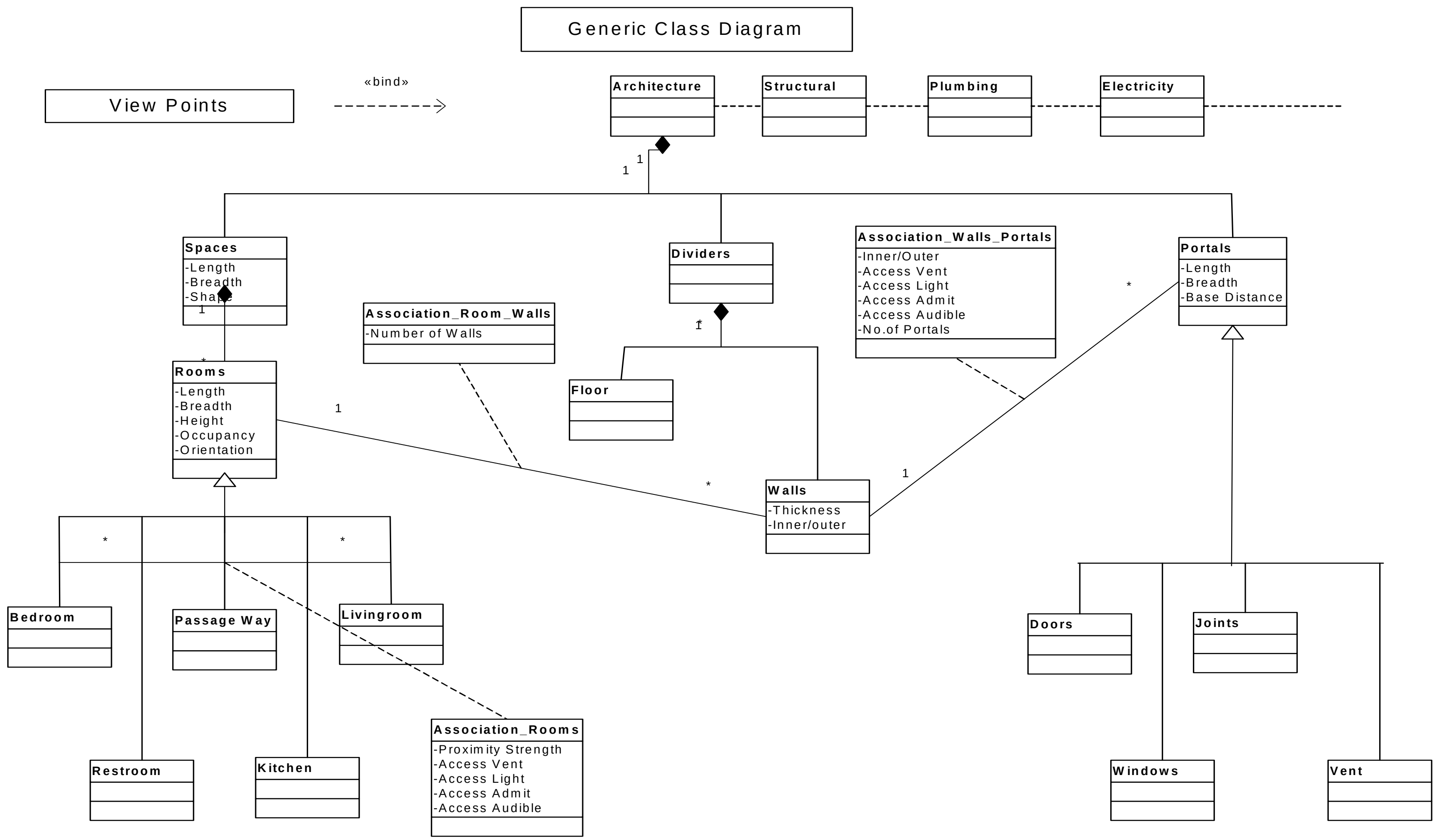
Background—System Structure

- The complete architectural viewpoint is divided in to three sub classes:
  - Spaces
  - Dividers
  - Portals

- Relationship
  - between different rooms - (Association_Rooms)
  - between rooms and walls (Association_Rooms_Walls)
  - between walls and portals (Association_Walls_Portals)

- The properties of these association classes
  - Proximity strength - address the proximity issue between different rooms
  - Access Type – What type of access is available
  - Access Vent – Is it for ventilation purpose
  - Access Light – Is it allowing light to pass through i.e. is it transparent
  - Access admit – Is it allowing people to enter or exit

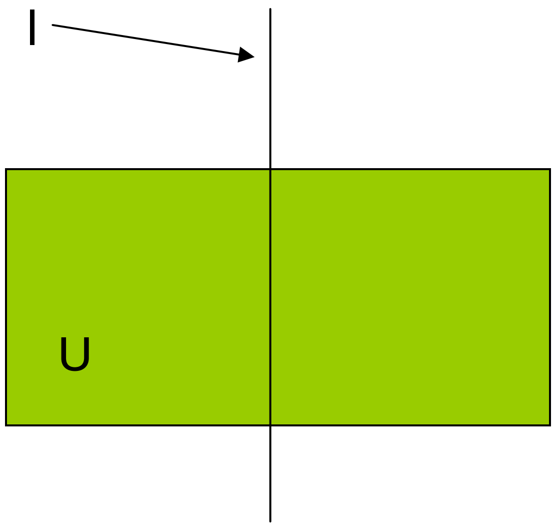
Background—System Structure



Spatial Logic & Its Application

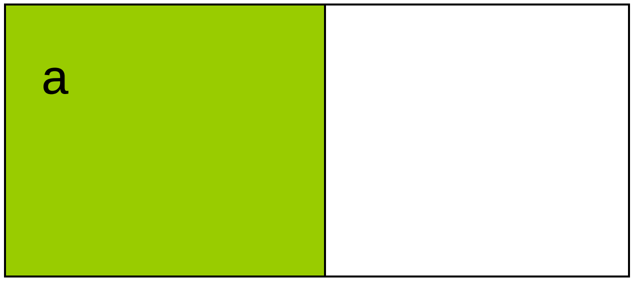
Concept of Hyperplanes

- A conceptual border that divides two sets of points
- Each half forms a halfplane
- Mathematically, it can be represented as



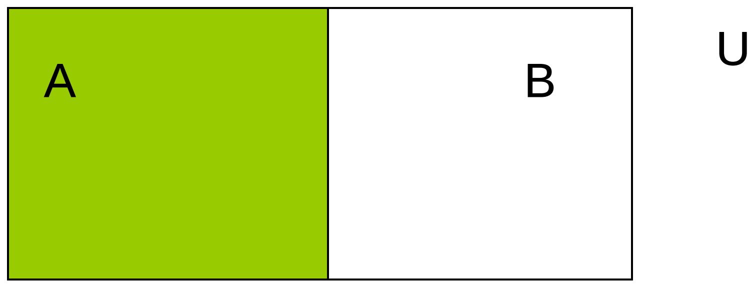
Half planes

- Represents spaces symbolically without any reference to a particular coordinate system
- The predicate hp(x) is a general representation of a halfplane, according to its truth value
- E.g.. ***hp(a)***



Halfplanes

- ***U = {p(x, y)}***
- ***U*** always can be divided into exactly two subsets A and ***B,*** defined by:
- A = {*p(x, y) : f(x,y) > 0}, and*
- *B* = {*p(x, y) : f(x,y) <0}*
- f(x,y) is a continuous function in U.
- A and ***B*** are non-empty, closed sets.
- Therefore A and ***B*** have the following characteristics:
- A ∩ ***B*** is Ǿ, and
- A U ***B*** is U.



Defining Regions using Halfplanes - 1

- Given n halfplanes, a region ***R*** is defined by a conjunctive formula of n hp(x), as ***R*** is $\boldsymbol{hp(a_1) \wedge hp(a_2) \; .. \wedge hp(a_n)}$.
- Since each halfplane can have truth value True or False, each region is an ***interpretation*** of the Formula above.
- For our floor plan:

$$U \rightarrow hp(\alpha) \wedge hp(\beta) \wedge hp(\gamma) \wedge hp(\delta)$$

Constraints

- $hp(b) \rightarrow \neg hp(c)$
- $hp(c) \rightarrow \neg hp(b)$
- $hp(b) \rightarrow hp(a)$
- $\neg hp(b) \rightarrow \neg hp(a)$

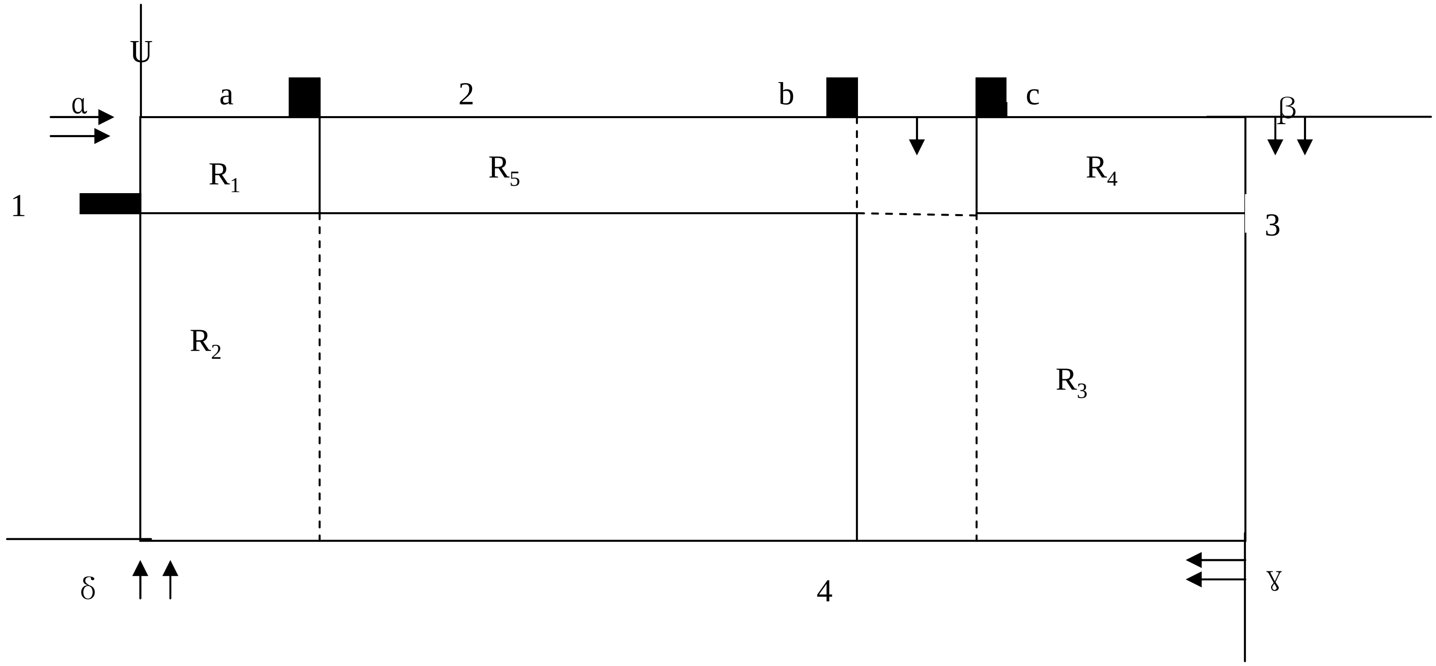
Defining Regions using Halfplanes -2

$$hp(\gamma) \rightarrow hp(b) \rightarrow hp(a)$$

$$hp(\gamma) \rightarrow hp(b)$$

$$hp(\alpha) \rightarrow hp(c)$$

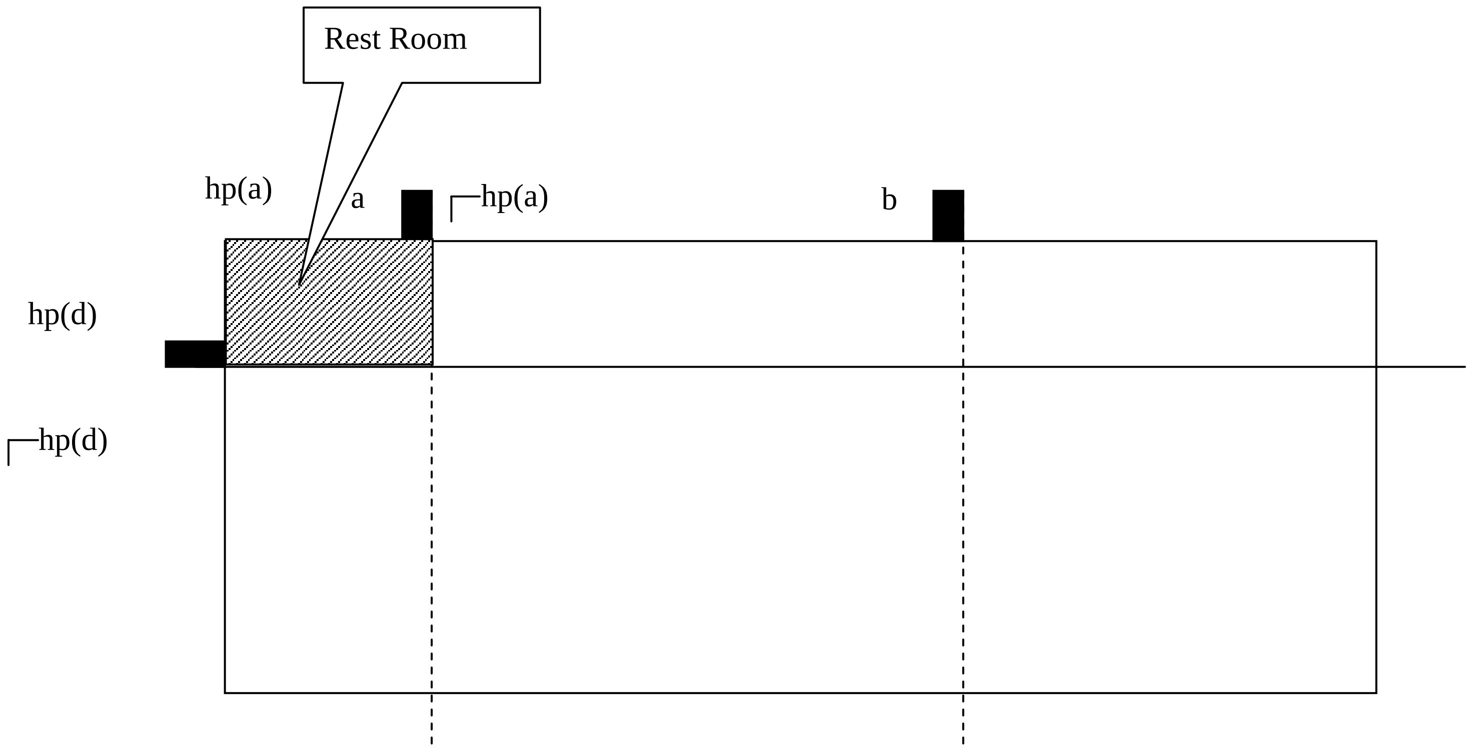
$$hp(\delta) \rightarrow hp(d)$$



Restroom R1

$$hp(a) \wedge hp(b) \wedge hp(d) \wedge \neg hp(c)$$

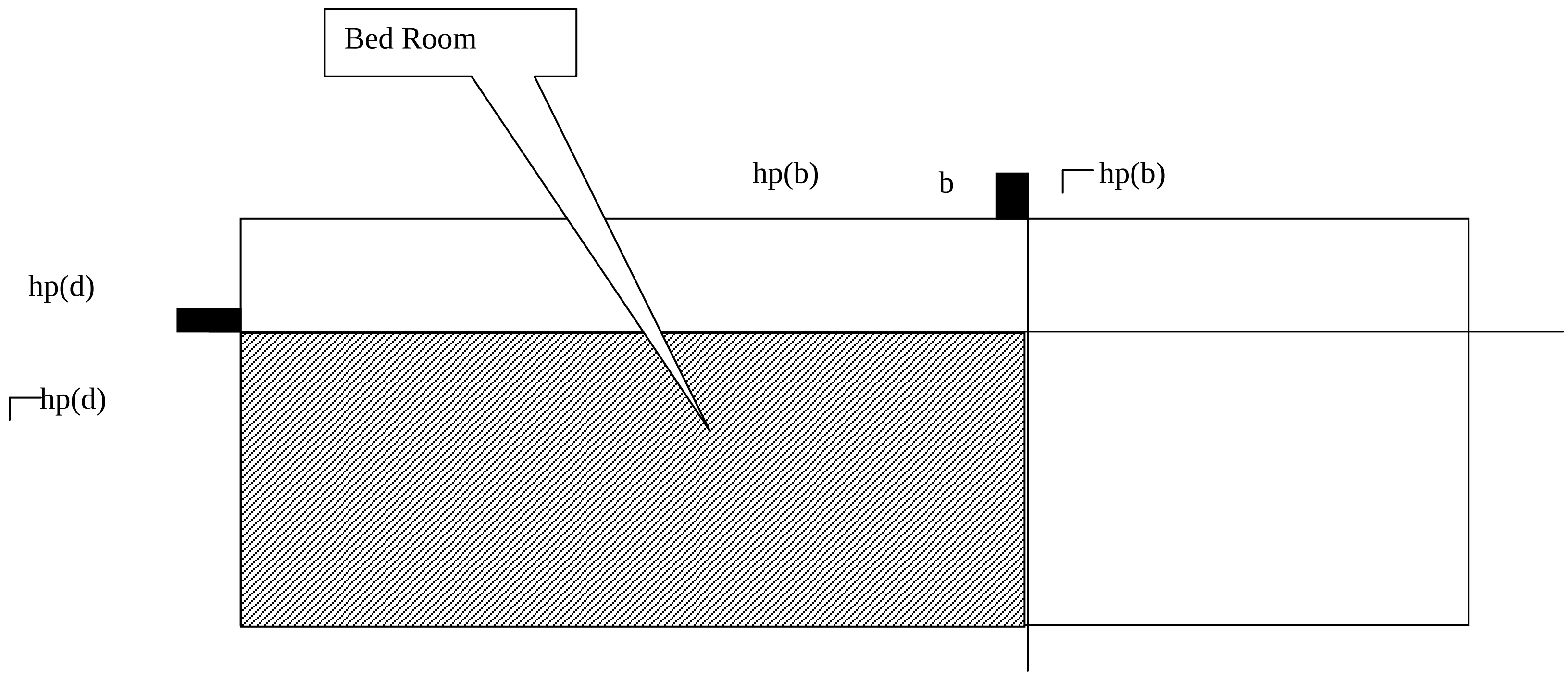
$$hp(a) \wedge hp(d)$$



Bedroom R2

$$hp(a) \wedge hp(b) \wedge \neg hp(d) \wedge \neg hp(c)$$

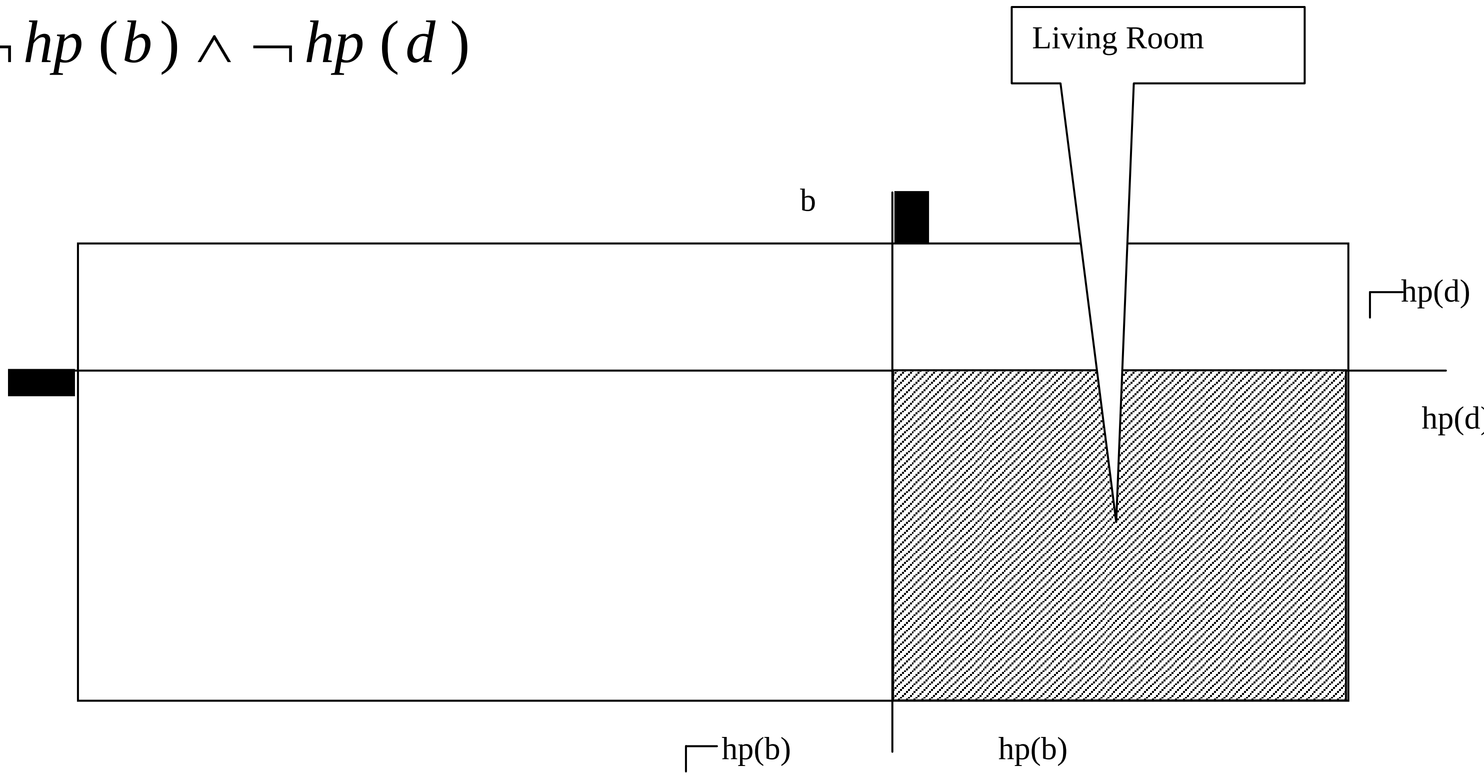
$$hp(b) \wedge \neg hp(d)$$



Living room R3

$$\neg hp(a) \wedge \neg hp(b) \wedge \neg hp(d)$$

$$\neg hp(b) \wedge \neg hp(d)$$



Verifying the presence of a region

S.No	hp(a)	hp(b)	hp(c)	hp(d)	R
1	False	False	False	False	True
2	False	False	False	True	True
3	False	False	True	False	True
4	False	False	True	True	True
5	False	True	False	False	True
6	False	True	False	True	True
7	False	True	True	False	False
8	False	True	True	True	False
9	True	False	False	False	False
10	True	False	False	True	False
11	True	False	True	False	False
12	True	False	True	True	False
13	True	True	False	False	True
14	True	True	False	True	True
15	True	True	True	False	False
16	True	True	True	True	False

Verifying the presence of the region

Room	Region	S.No.	R
Restroom	R1	13	True
Bedroom	R2	14	True
Living room	R3	3	True
Kitchen	R4	4	True
Passageway	R5	6	True

Border adjacency

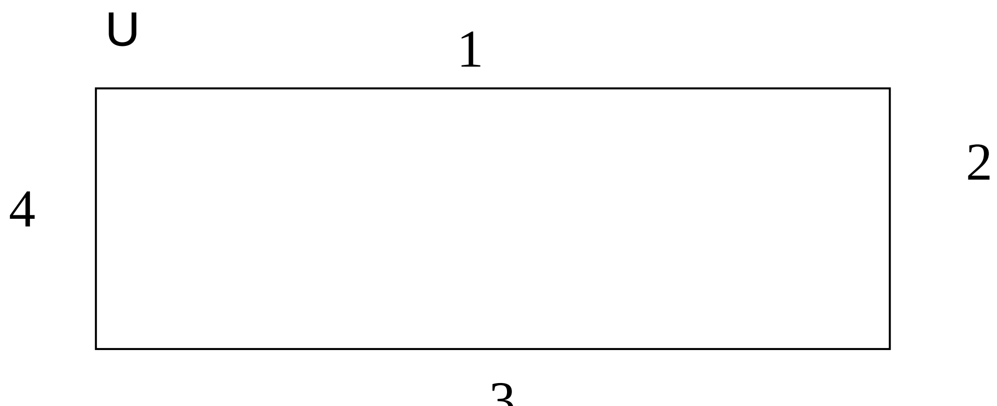
- Given a minimal description of a region ***R*** expressed **by hp(x_1)** $\wedge$ hp(x_2)$\wedge$. . . hp(x_n), a region R_{adj} is **border adjacent** to ***R*** iff it differs in only one hp(xi), such as hp(xi) in ***R*** is $\neg$ hp(xi) in R_{adj}.

Border adjacency for R1 and R2

- Restroom $hp(a) \wedge hp(d)$
- Bedroom $hp(b) \wedge \neg hp(d)$
- From the constraints hp(b) $\rightarrow$ hp(a)
- Thus, restroom is region adjacent to the bedroom as it differs in only in one hp(xi) i.e. [hp(d)]

Relative position

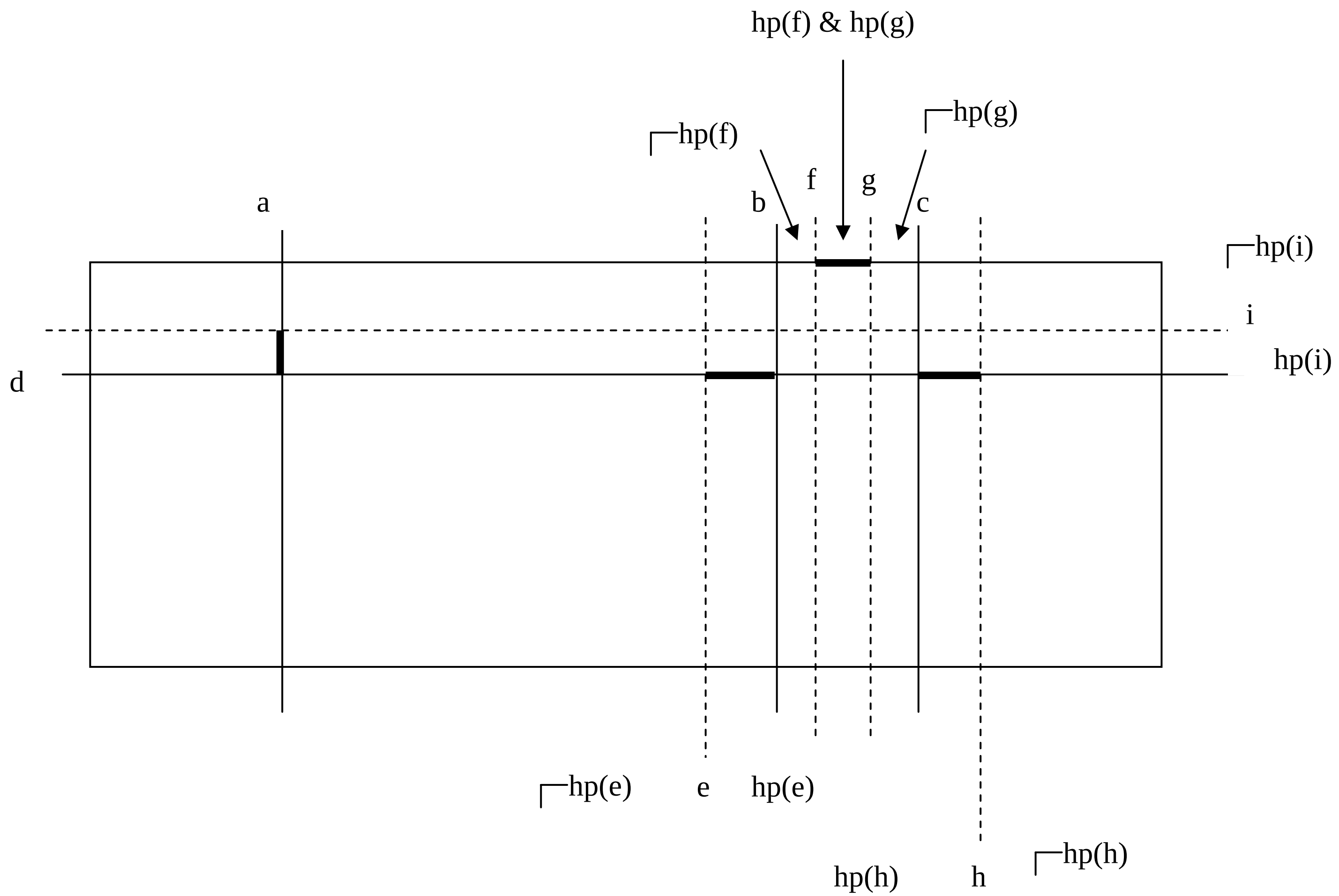
Half plane	Begin end	Denotation	Abbreviation
a	1-3	Left	L
b	1-3	Centre	C
c	1-3	Right	R
d	4-2	Above	A



Relative position R1 and R2

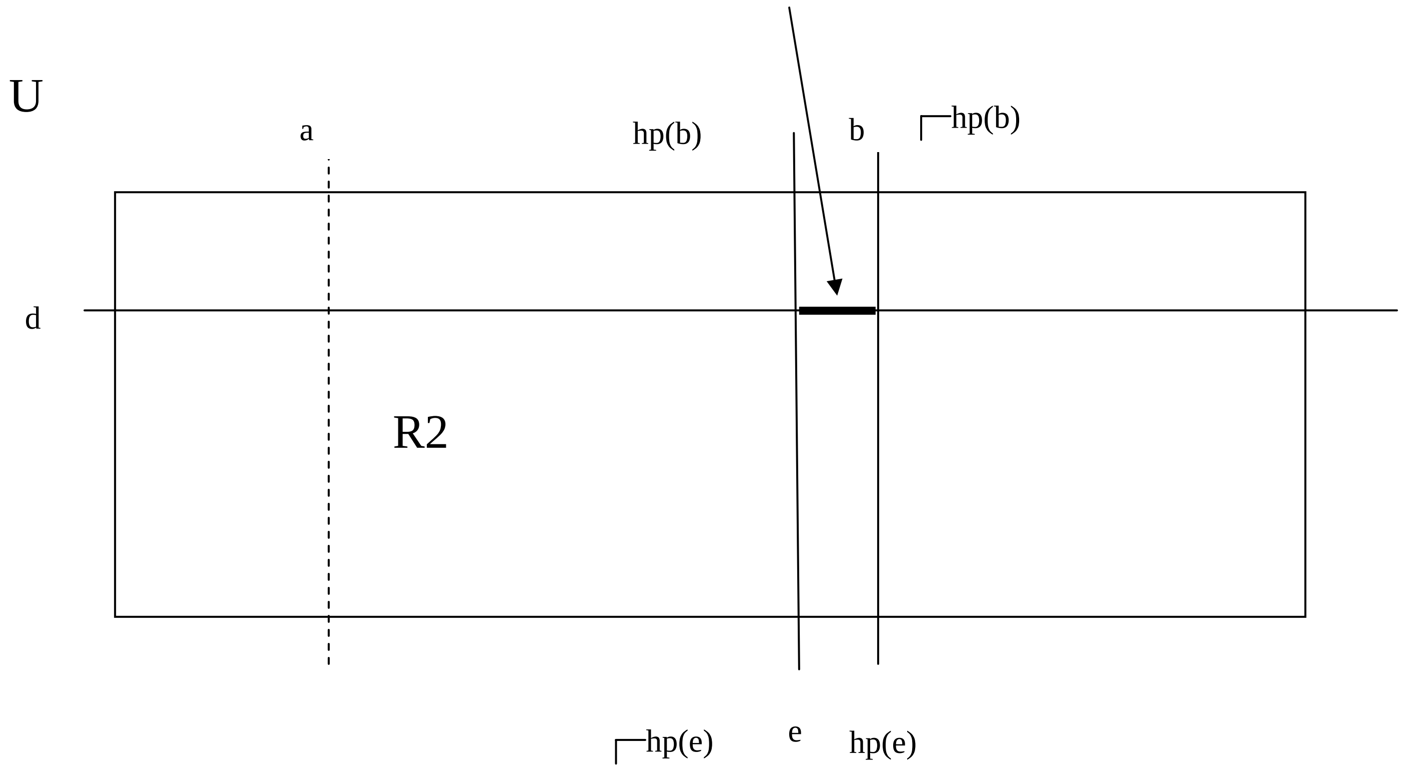
- Restroom $hp(a) \wedge hp(d)$
- Bedroom $hp(b) \wedge \neg hp(d)$
- The difference is restroom hp(d) and bedroom $\neg$hp(d) therefore topographically restroom is above bedroom

Adding portals

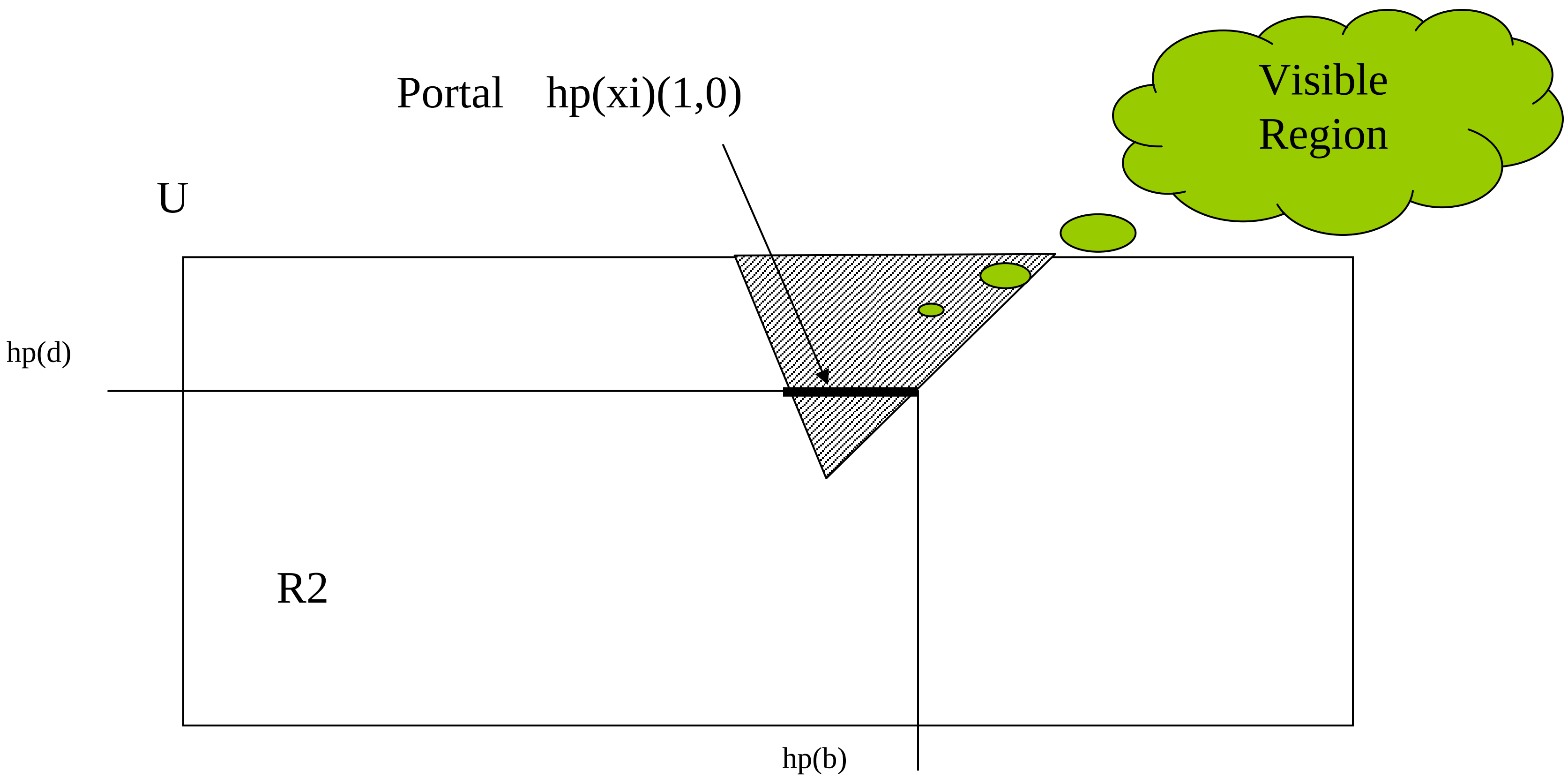


Representing the bedroom door

$$hp(d) \wedge \neg hp(d) \wedge hp(b) \wedge hp(e)$$



Visibility through the portals



Software Packages Used

- MS Visio
- MS Office

References

- **Papers**

  - A logic-based framework for shape representation by Jose C Damski and John S Gero
  - A Referential Scheme for Modeling and Identifying Spatial Attributes of Entities in Constructed Facilities by M. Kiumarse Zamanian & Steven J. Fenves
  - Implementing Topological Predicates for Complex Regions by Marcus Schneider
  - A Spatial Logic based on Regions and Connection by David A. Randell, Zhan Cui & Anthony G. Cohn

- **Class Notes**

Thank You!