

# An Alternative Measure of Public Transport Accessibility based on Space Syntax

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- Hierarchical Network Connectivity  
in Space Syntax
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# 1. Introduction

## 1. Introduction

### Introduction

- Public-oriented transport policy
  - City of Seoul recently reformed the bus system.
  - Accessibility is a key policy requirement for reorganizing the public transport network.
  - Public transport routing problems are complicated.
- An alternative accessibility measure using *Space Syntax*
  - *Path-based* not zone-based
  - *Topology-based* not conventional cost-based
  - *Depth-based* : more transfers means *deeper* connectivity
  - Tested on a CBD of Seoul

## 2. Hierarchical Network Connectivity in Space Syntax

### 1. Introduction

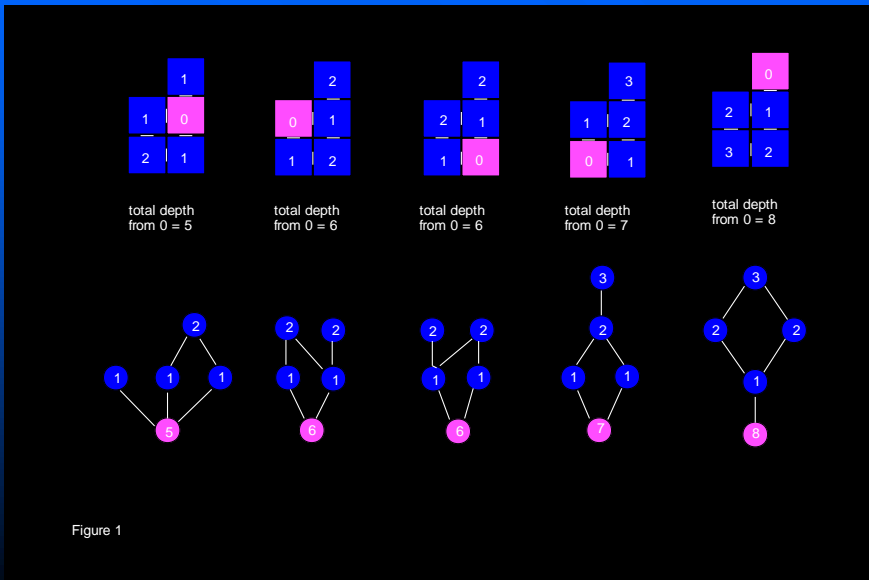
## Space Syntax

- Compute the connectivity of urban or architectural spaces (Hiller 1996).
- Model a spatial structure as *axial lines* and compute spatial indices of a space based on '*the depth*' to other spaces



## 1. Introduction

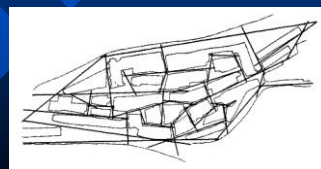
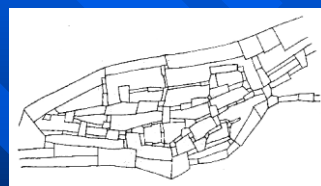
# Space Syntax



## 1. Introduction

# Space Syntax

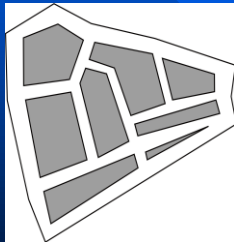
- Partition a given spatial structure into a set of “*fewest and fattest*” convex spaces
- Lay down the longest straight lines that passes through these convex spaces



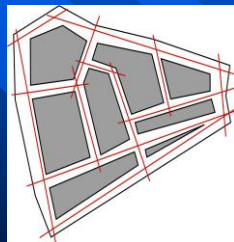
## Space Syntax

### ■ Space Syntax vs. Conventional network

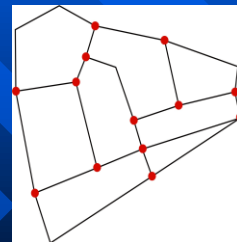
- Space syntax represents each line by a node and each intersection as an edge
- Conventional network → vice versa



a. a real street network



b. axial map

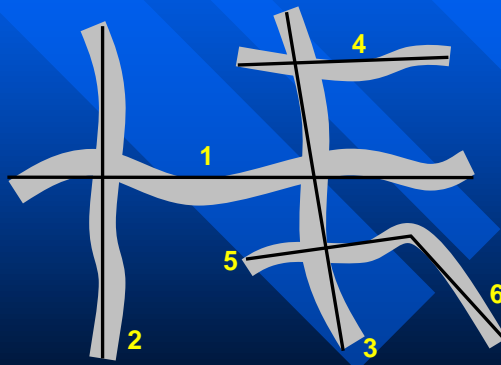


c. traditional network

Comparing the network representation of streets

## Hierarchical Network Configuration

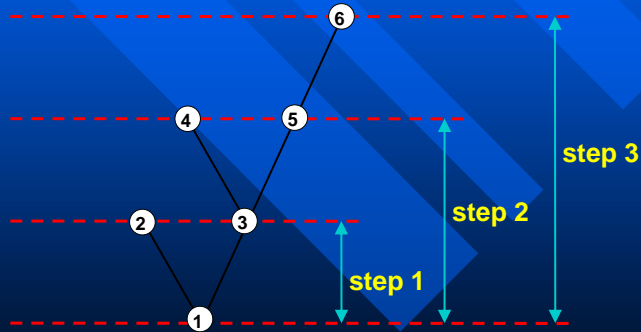
### ■ Street network in space syntax



## Hierarchical Network Configuration

### ■ Hierarchical structure of *street 1*

- Represent each spatial component with a node and a turn with a link connecting their respective nodes



## Hierarchical Network Configuration

### ■ This relationship is described by “*depth*”.

- Depth of one node from another can be measured by counting the number of steps (or turns) between two nodes.

### ■ Total Depth (*TD*)

- $TD_1 = 1 \times 2 + 2 \times 2 + 3 \times 1 = 9$

$$TD_i = \sum_{s=1}^m s \times N_s$$

$TD_i$  : the total depth of node  $i$

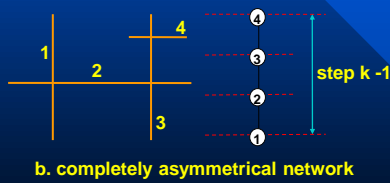
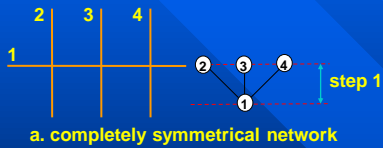
$s$  : the step from node  $i$

$m$  : the maximum number of steps extended from node  $i$

$N_s$  : the number of nodes at step  $s$

## Hierarchical Network Configuration

- Mean Depth (MD) =  $TD / (k-1)$
- Normalized Depth (ND)



$$MD = \frac{k-1}{k-1} = 1$$

\* k : the total number of nodes

$$MD = \frac{1+2+\dots+(k-1)}{k-1} = \frac{(k-1)k/2}{k-1} = \frac{k}{2}$$

$$1 \leq MD \leq \frac{k}{2}$$

$$0 \leq ND_i := \frac{2(MD-1)}{k-2} \leq 1$$

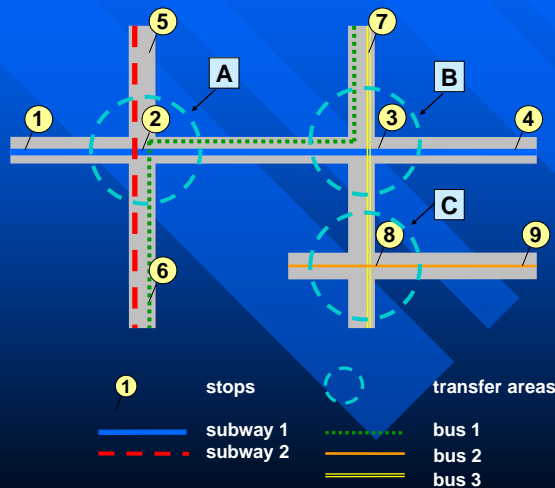
## 3. Applying to Public Transport

## Applying to Public Transport Problem

- Similarity between *turns* in space syntax and *transfers* in public transport
  - In space syntax, the deeper the depth from a space to others, the more difficult to move from that space to others.
  - In public transportation, cost generally increases as the number of transfers between different modes increases.

## Public Transport Network

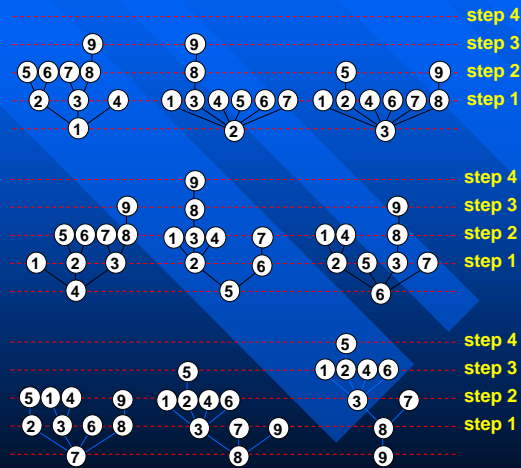
- A *transfer* from a vehicle to another is a *depth* between spaces.





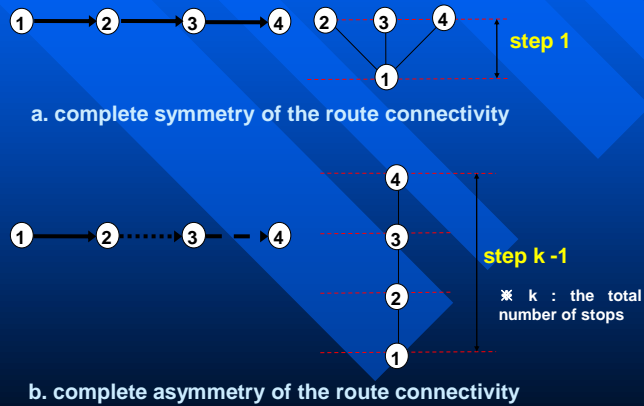
## Hierarchical Representation

- Mapping schematic route connectivity onto a graph



## Hierarchical Representation

- Symmetry and asymmetry of the route connectivity



### 3. Applying to Public Transport Problem

## Computing *Depths*

- Computing depth from each stop

Stop No.	TD	MD	ND	ND <sup>-1</sup>
1	14	1.750	0.214	4.67
2	11	1.375	0.107	9.33
3	10	1.250	0.071	14.00
4	14	1.750	0.214	4.67
5	17	2.125	0.321	3.11
6	13	1.625	0.179	5.60
7	12	1.500	0.143	7.00
8	14	1.750	0.214	4.67
9	21	2.625	0.464	2.15

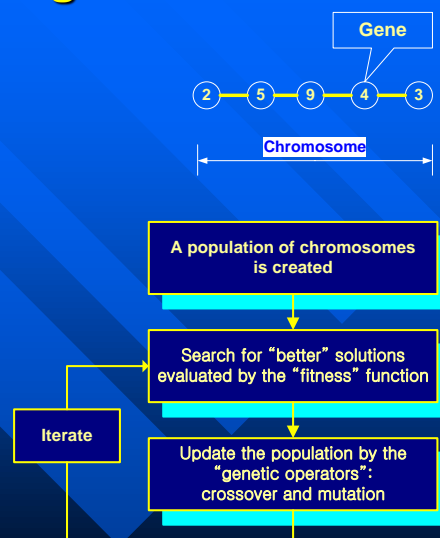
## 4. Computing O-D Paths using GA

## Generating Paths using GA

- Computing depth of a stop requires finding paths from that stop to all others, each of which being *the minimum-cost path*.
- In this study, the minimum-cost path is the one having the *minimum number of transfers* between the O-D.

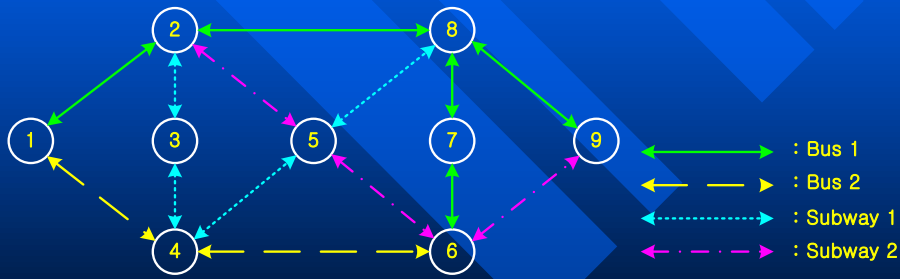
## Genetic Algorithms

- A global search process on a certain population of chromosomes by gradually updating the population
- Exploiting the best solutions while exploring the search space



## Computing O-D Paths

- An example network with different types of vehicles.
- Transfers do not happen at nodes 3 or 7. The rest nodes allow the traveler to transfer to another mode.



An example of multi-modal network

## Computing O-D Paths

- Representation
  - Ex: (1, 2, 5, 6, 9)
- Initialization
  - C1 = (1, 2, 8, 9)
  - C2 = (1, 4, 5, 6, 9)
  - C3 = (1, 2, 5, 6, 7, 8, 9)
  - ...
- Evaluation
  - Rate potential solutions by their fitness
  - Here, the total transfers from the origin to the destination at chromosome C

$$eval(C) = gene\_transfers(x)$$

## Computing O-D Paths

### ■ Selection

- Good chromosomes are preserved instead of participating in the mutation or crossover.

### ■ Genetic Operators

- Some members in the population are altered by two genetic operators: *crossover* and *mutation*.

## Computing O-D Paths

### ■ Genetic Operators (cont'd)

#### • Crossover

- » a common node (e.g. Node 5) is selected and the portions of chromosomes after this node are crossed generating new children.

$C2 = (1, 4, \underline{5}, 6, 9)$        $\longrightarrow$        $C2' = (1, 4, \underline{5}, 6, 7, 8, 9)$   
 $C3 = (1, 2, \underline{5}, 6, 7, 8, 9)$        $\longrightarrow$        $C3' = (1, 2, \underline{5}, 6, 9)$

#### • Mutation

- » An arbitrarily selected gene becomes a temporary origin.
- » The portion after this is regenerated.

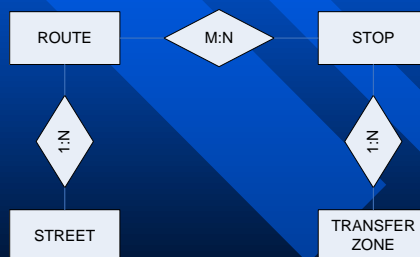
$C2 = (1, 4, \underline{5}, 6, 9)$        $\longrightarrow$        $C2' = (1, 4, \underline{5}, 2, 8, 7, 6, 9)$

## 5. The Case Study

### 5. The Case Study

## Building GIS Data

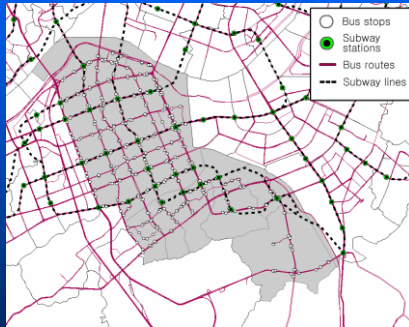
- Currently used GIS data can not capture the complex relationship in public transport
- Make GIS network data usable
  - Organized them into a spatially integrated data set
  - Added some attribute data tables and build relationship using relational DB



E-R diagram of public transport network

## Applying to a Site

- Test Site : a CBD of Seoul
  - High complexity of multimodal structure



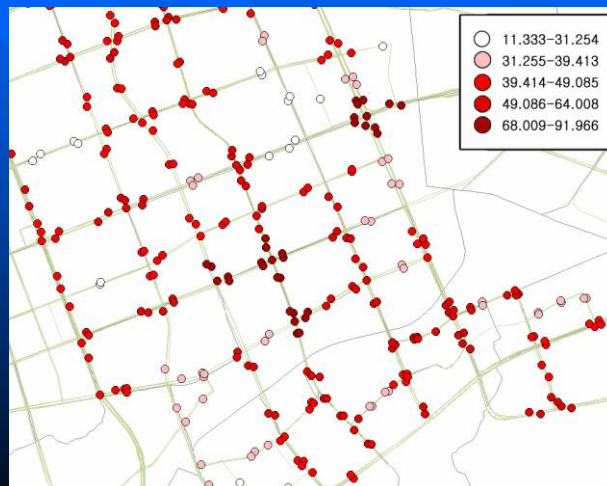
Public transport network



Transfer zones

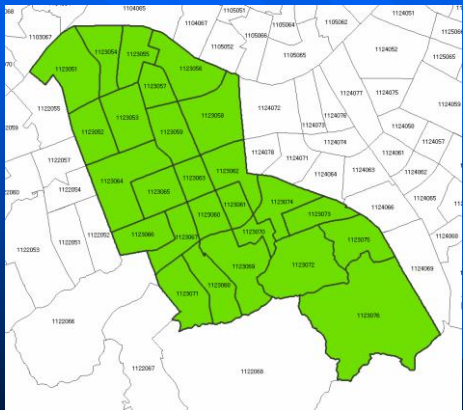
## Applying to a Site

- Integration values ( $ND^{-1}$ )



# Applying to a Site

- O-D survey zones of test site and O-D matrix



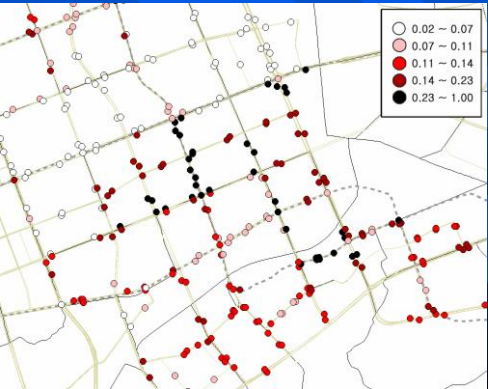
OD	112351	112352	112353	112354	112355	...	112375
112351	1951	940	1036	1426	555	...	290
112352	1174	8498	598	1340	147	...	124
112353	906	292	853	488	110	...	32
112354	659	1911	336	408	0	...	140
112355	398	185	223	0	160	...	47
...	...	...	...	...	...	...	...
112375	442	56	35	76	...	...	515

# Applying to a Site

- The weighted accessibility of stops

$$A_i^s = \frac{I_s}{\sum_j T_{ij}} = \frac{I_s}{O_i}$$

$A_i^s$  : accessibility of stops  $s$  in zone  $i$   
 $I_s$  : Integration of stop  $s$   
 $T_{ij}$  : the number of trips between origin  $i$  and destinations  $j$   
 $O_i$  : the total number of trips originating in zone  $i$



The weighted accessibility



## 6. Discussion

### 6. Discussion

#### Modifying the Depth-based Accessibility

- We considered only '*depth-penalty*', the *number of transfers*
  - Not taking into account traditional travel costs (distance, travel time...)
- Combining the depth-based accessibility measure and the traditional accessibility
- Typical accessibility

$$A_i = \sum_j O_j d_{ij}^{-1}$$

$A_i$  : Accessibility of person  $i$  or zone  $i$   
 $O_j$  : Number of opportunities at distance  $j$  or zone  $j$   
 $d_{ij}$  : Separation between  $i$  and  $j$

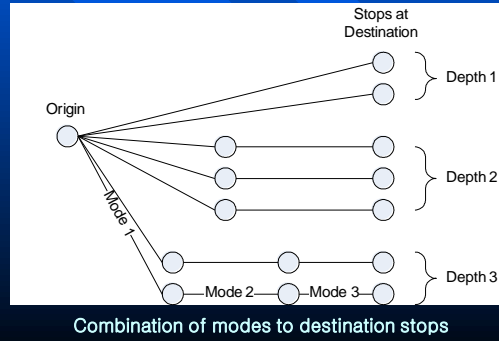
## 6. Discussion

### Modifying the Depth-based Accessibility

#### ■ Accessibility considering transfers and travel costs

$$A_i = \sum_d^{D_i} f(w_d) \left( \sum_n^{N_d} f(t_n) \right)$$

$D_i$  : maximum number of depths from node  $i$   
 $N_d$  : number of destination nodes at depth  $d$   
 $t_n$  : travel cost between  $i$  and  $n$   
 $w_d$  : weight at depth  $d$



## 6. Discussion

### Modifying the Depth-based Accessibility

#### ■ Decompose stop-related impedances and travel costs

- » Taking or changing to a vehicle may become diverse depending on the circumstances one may face with,
- » for instance, walking distance to the next bus stop or waiting time at transfer zones.

$$A_i = \sum_d^{D_i} \sum_p^{P_d} \sum_m^{M_p} f(t_m, w_m)$$

$D_i$  : maximum number of depths from node  $i$   
 $P_d$  : number of paths at depth  $d$   
 $M_p$  : number of modes composing path  $p$   
 $w_m$  : weight related with choosing mode  $m$

## 7. Concluding Remarks

### Concluding Remarks

- An alternative accessibility measure of public transport network.
- An analogy between the concept of *depths* in space syntax and the number of *transfers* in the public transportation.
- Compared the depth-only measure and weighted measure by O-D
- Suggested a general form of equation that can incorporate travel cost
- The accessibility measure at individual routes level may be useful for policy makers
  - Slow GA processes can be improved by using parallel processing

