A Nested Dynamic Discrete Choice Model of Collective Behaviors incorporated in Spatial Reference Group under Disaster Situation

BinN International Research Seminar #01-3
July 12th, 2014

The University of TOKYO
Junji URATA, Eiji HATO

Outline of Today's Presentation

1. Introduction & Main Idea
2. Methodology
3. Application
4. Conclusions

Introduction

We focus on collective behaviors of local residents under a disaster situation

- Collective behavior : Evacuation with others, Distributing information
- The collective behaviors influence their future states and their evacuation timings
- The supported people shrink danger but the supporting people grow danger through the collective behaviors
- Population synchrony trigger a concentration of collective behaviors in a local space.

Our Purpose :

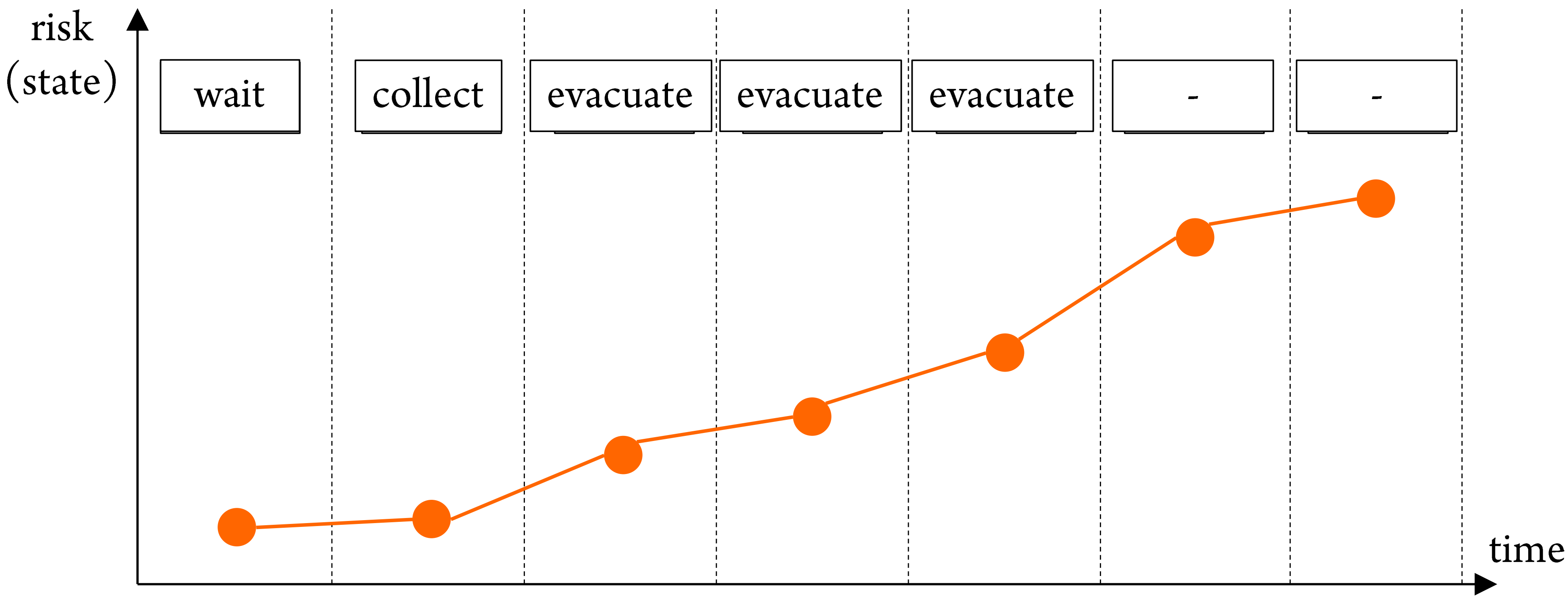
- We model a process of contributing collective behaviors in a devastated area.
- A efficient local evacuation rule and a prompt information propagation system are needed and these things should be based on the collective behavior predictions

Our model has two main factors :

- specify the expectations of the future utility and risk by the introduction of a dynamic discrete choice model
- include the influence of others behaviors among their groups

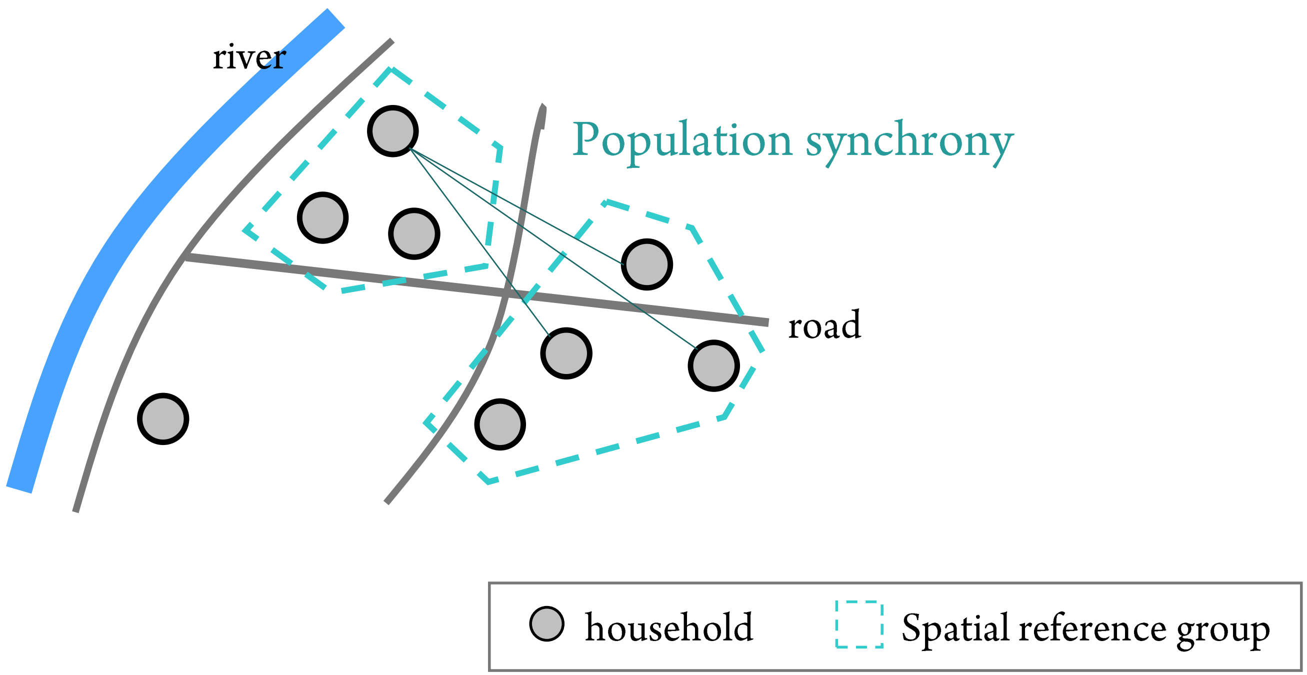
Main Idea 1: Dynamic Discrete Choice

- Risk aversion behaviors take time and people should choose their action for their future states.
- They have the expectations of their future states and they can choose their optimal behaviors in every time slot.



Main Idea 2: Spatial Reference Group

- Residents who are located near have an approximately-same risk
- People who can't decide their behaviors by themselves refer the behaviors of neighborhoods
- A group consisting of people who are located near work as a reference group
- The effect of population synchrony are produced among the reference groups



2. Methodology

Choice Structure & Influence from Others

We employ the field as a virtual decision maker because we simply model influence of others' behaviors

--Comparing an "individual" and a "field" as a decision maker--

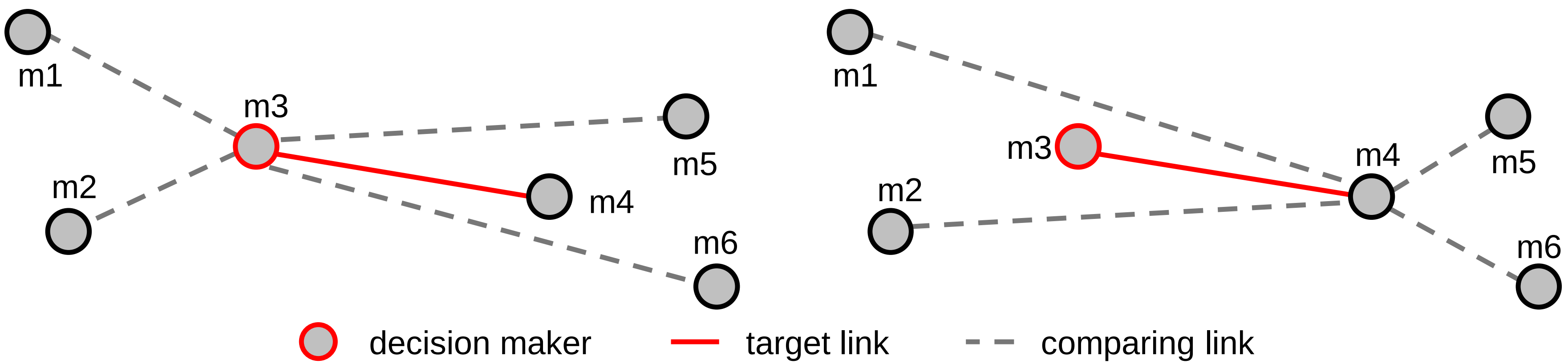
Case I. An "individual" as a decision maker

- Others' behaviors for a decision maker and for a counterpart should be considered in their decision making
- We add all the decision maker's behaviors to describe the whole area.
- The number of factor combinations is $(n-1) \times (n-2) \times n$

n: the number of people in the field

a) Considering Others acts for him/her

b) Considering Others acts for the counterpart



Choice Structure influenced by Others

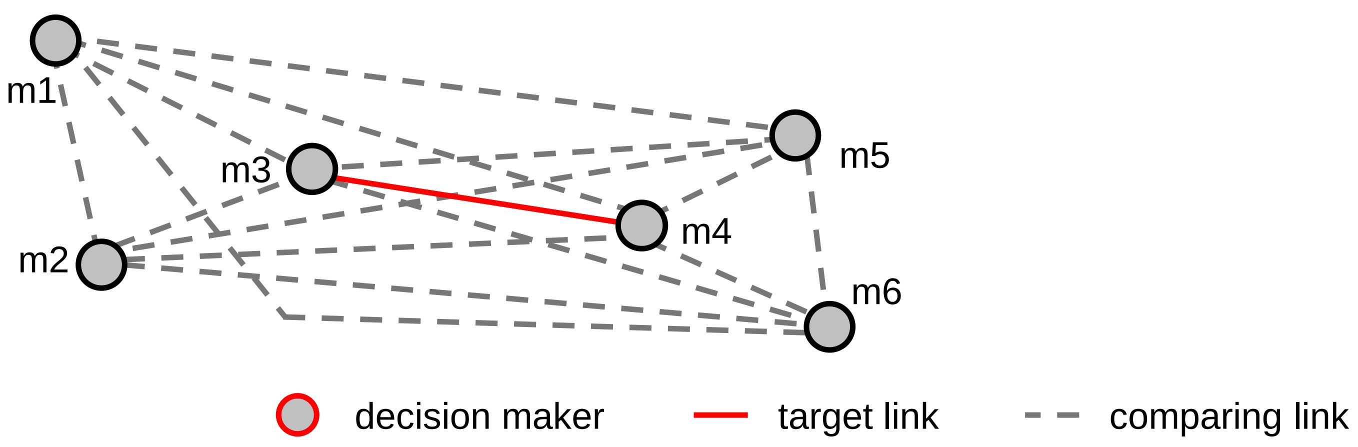
We employ the field as a virtual decision maker because we simply model influence of others' behaviors

--Comparing an "individual" and a "field" as a decision maker--

Case II. A "field" as a decision maker

- The "field" compare all links which are the candidates of making collective behaviors and choose the optimal one.
- The number of all links is ${}_nC_2$ (=n(n-1)/2)   n: the number of people in the field

c) Comparing all links



Formulation of Dynamic Discrete choice model

Explain generally the formulation of dynamic discrete choice model of a single-agent type

Value function

$$V(s_t) = \max_{j_t} \left\{ E_t \left(\sum_{\tau=t}^{\infty} \beta^{\tau-t} u_{j_\tau}(s_t) \right) \right\} \quad (1)$$

$$V(s_t) = \max_{j_t} \left\{ u_j(s_t) + \beta \int V(s_{t+1}) p(ds_{t+1} \mid s_t, j_t) \right\} \quad (2)$$

$$v(j, x_t) = u(j, x_t) + \varepsilon_t(j) + \beta \sum_{x_{t+1}} \bar{V}(x_{t+1}) p(x_{t+1} \mid x_t, j_t) \quad (3)$$

Choice Probability

$$P(j_t \mid x_t, \theta) = \frac{\exp\left(u(j, x_t) + \beta \sum_{x_{t+1}} \bar{V}(x_{t+1}) p(x_{t+1} \mid x_t, j_t) \right)}{\sum_{j_t} \exp\left(u(j, x_t) + \beta \sum_{x_{t+1}} \bar{V}(x_{t+1}) p(x_{t+1} \mid x_t, j_t) \right)} \quad (4)$$

$t : time$ $\quad$ $\beta : time\ discount\ rate$ $\quad$ $p(ds_{t+1} \mid s_t, j_t) : transition\ probability$

$j : choice$ $\quad$ $u : utility$ $\quad$ $\theta : parameters$

$s : state$ $\quad$ $x : observable\ state$ $\quad$ $\varepsilon : unobservable\ state,\ i.i.d.\ Gumbel\ distribution$

We now define the utility function of the field.

Inequality Averse for Link Utility

A preference of inequality averse is a factor for contributing collective behaviors

- The preference occurs from the difference of states between the two
- Some collective behaviors from a preference of inequality averse expose themselves to danger
- They make collective behaviors not only for their security but also for others' security

Formulate the link utility by using a travel cost and a gain of inequality averse

A link utility : a state between the two which is influenced by collective behaviors

Utility: make a collective behavior $$u_{ij}^{l} = -c_{ij}^{tr} - (1-\alpha)c_{ij}^{ine} \quad (5)$$

Utility: non-make $$u_{ij}^{l,non} = -c_{ij}^{ine} \quad (6)$$

$c_{ij}^{ine} = |x_i - x_j|$: Inequality cost

c_{ij}^{tr} : Travel Cost

$\alpha \in (0,1)$: Parameter of inequality release

x_i : State (represent their risk)

Dynamics of Link Utility

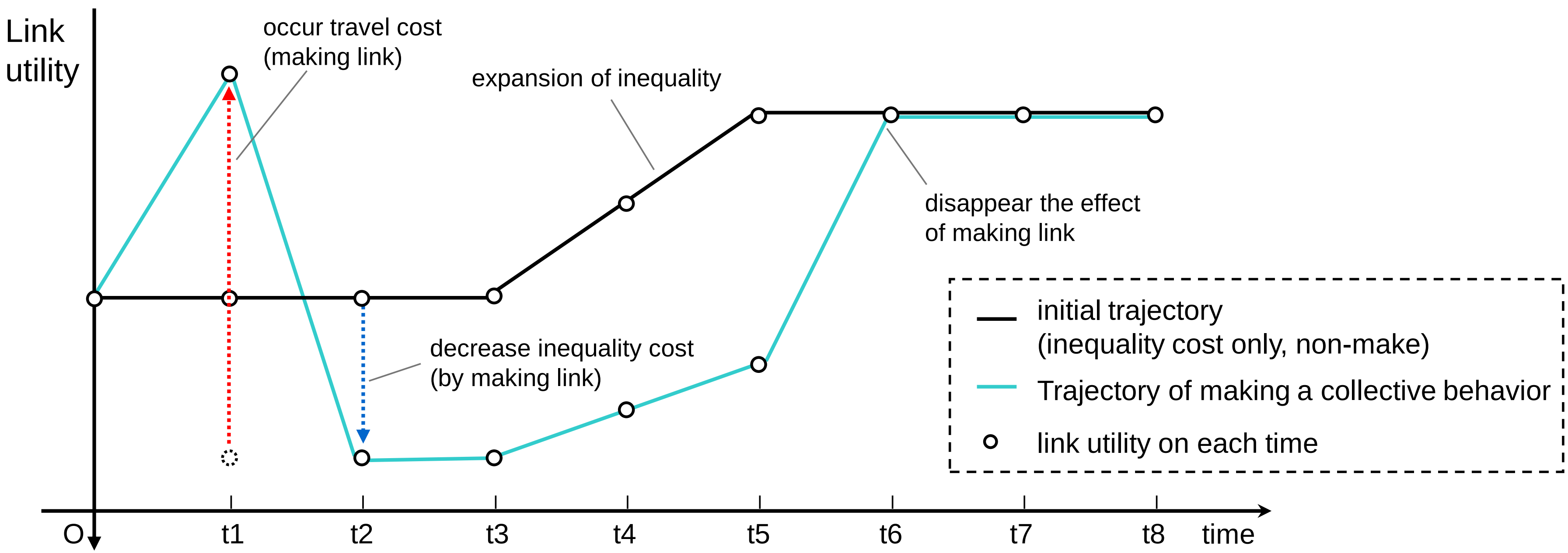
The link utility change by time along their risks and behaviors

- They cost travelling to others at the time slot and get a gain of inequality averse
- After the travel, they don't carry the cost but keep a gain of inequality averse

$$u_{ij}^{l}(t) = -(1-\delta_{ij}(t)\alpha)\,|\,x_i(t) - x_j(t)\,| - \delta_{ij}(t)c_{ij}^{tr}(t) \qquad (7)$$

$\delta_{ij}(t) = 1:$ Link ij make a collective behaviors at time t

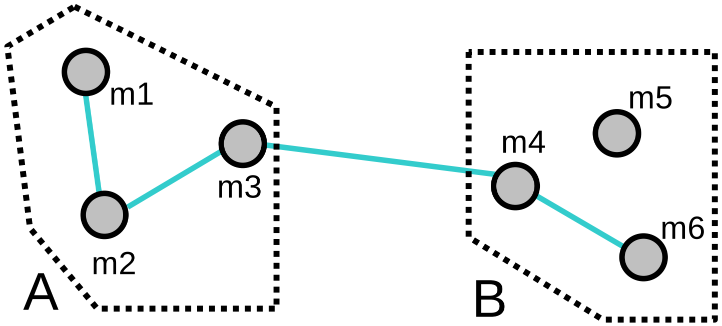
$\delta_{ij}(t) = 0:$ otherwise



Setting Spatial Reference Group for Links

1) Divide Basic Groups

- divide basic groups by spatial characteristics



2) Set Intra and Inter Links by basic groups

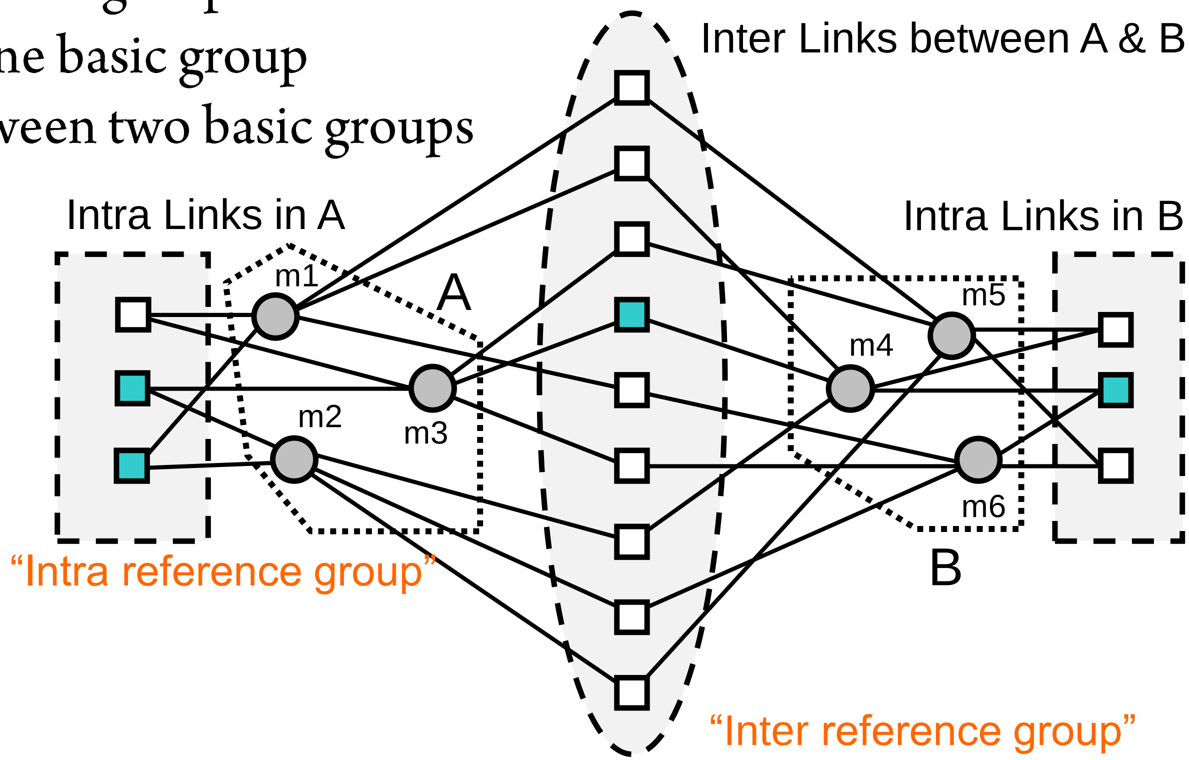
- Intra links are composed in one basic group
- Inter links are composed between two basic groups

- A reference group is constructed of intra links in one basic group

→ “Intra reference group”

- A reference group is constructed of inter links between two basic groups

→ “Inter reference group”



link | node | basic group | reference group | make a collective behavior

Reasons for Introduction of Reference Group

1. Taking on the characters of links
- The reference groups can aggregate the links with taking on their characters
- They are common states (from risk and travel) because they are located near

Define the utility of the reference groups as the average of their link utilities

$$u^r(r, X_t^r) = \frac{\sum_{l_{ij} \in r} u_{ij}^l(t)}{n_r} \qquad (8)$$

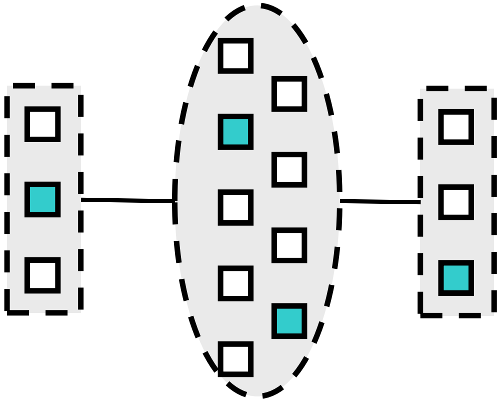
n_r : *the number of links in group r*

2. Describe the effect of population synchrony by their norm under disaster
- People are hard to decide their behavior by themselves because a disaster is a super low-frequency phenomenon
- People refer the behaviors of neighborhoods because people who can't decide their behaviors by themselves need a norm under a disaster situation
- A group consisting of people who are located near work as a reference group

Synergetic and Disjunction Effect

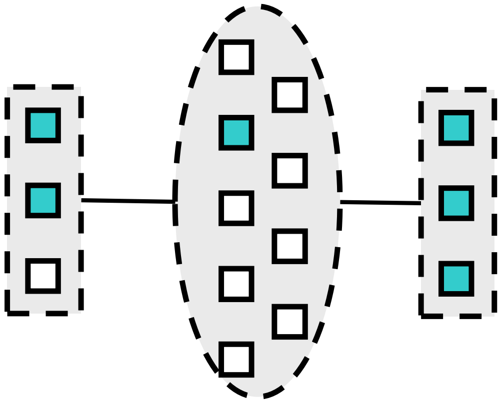
1. Synergetic Effect

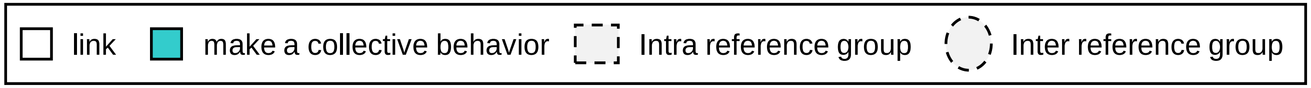
- Links in the same reference group have the same norm
- When a few links make collective behaviors, other links also made the behaviors by their norm



2. Disjunction Effect

- This effect are produced in a inter reference group
- When both-side intra reference groups of a inter reference group have many collective behaviors, it is hard to make collective behaviors in the inter reference group of inter links





Add the number of collective behaviors in the reference groups to the their utility

$$u'^{r}(r, X_t^r) = u^r(r, X_t^r) + f^{cg}(k^r(t)) + f^{dj}(k^r_{\text{inter}}(t)) \qquad (9)$$

X_t^r : *state of* r, k : *number of collective behaviors*, f^{cg}, f^{dj} : *function of effect*

Field Utility

We give the utility of the field based on the above

- The field choose a reference group which have a collective behavior and the rest of the groups inevitably don't have collective behaviors

The numerical vector of the collective behaviors in each group:

$$K(t+1) = \left(k_{r_1}(t), \ldots, k_{r_{m-1}}(t), k_{r_m}(t)+1, k_{r_{m+1}}(t), \ldots, , k_{r_n}(t)\right)^T \tag{10}$$

Practically, the field decide this vector in each time.

Define the utility of the field as the sum of the utilities of the reference groups.

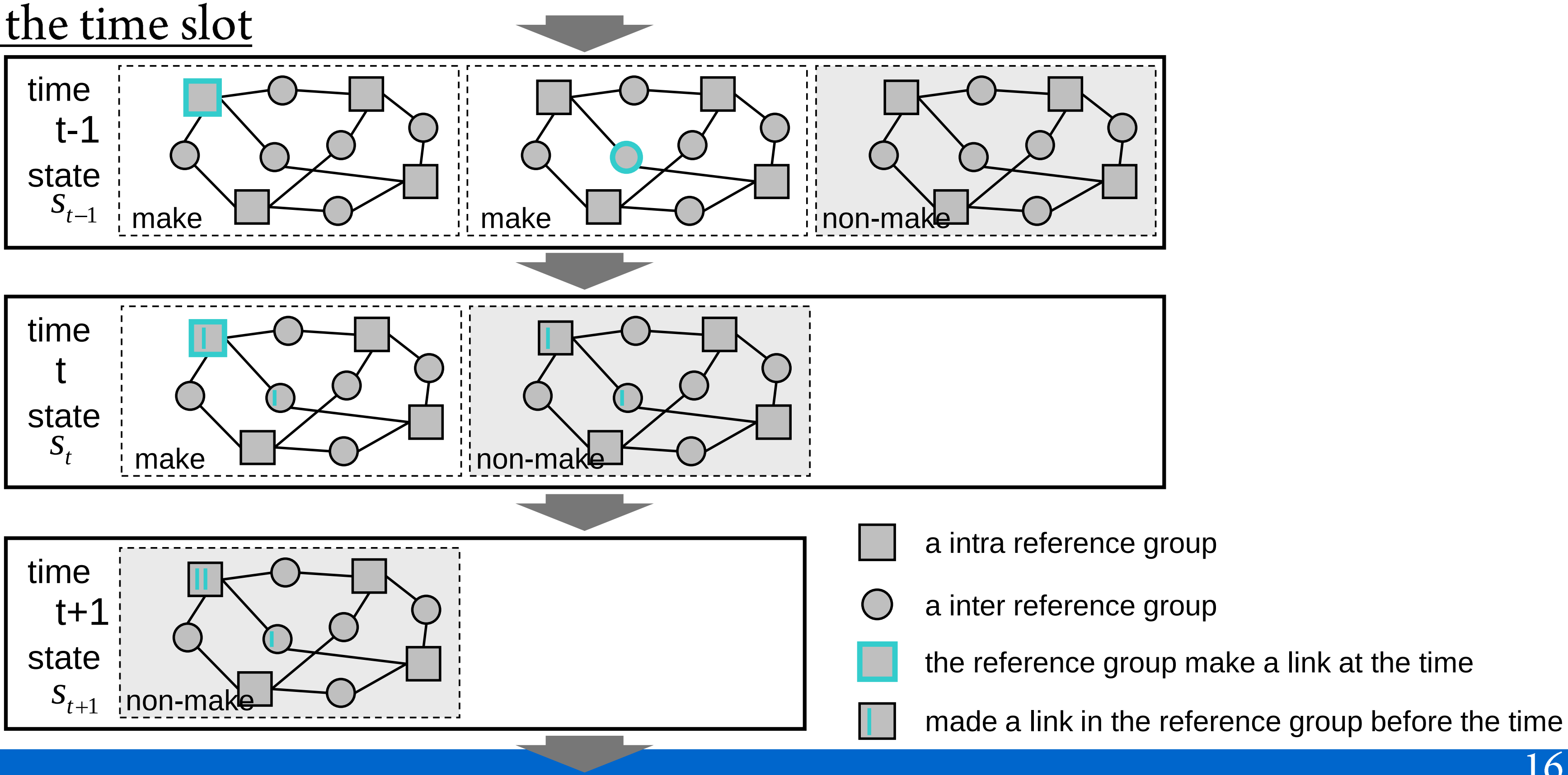
$$U^f(t, X_t) = \sum_r u'^r(r, X_t^r) \tag{11}$$

Formation Process for Dynamic Model

Set the time slot for the application of dynamic discrete choice model

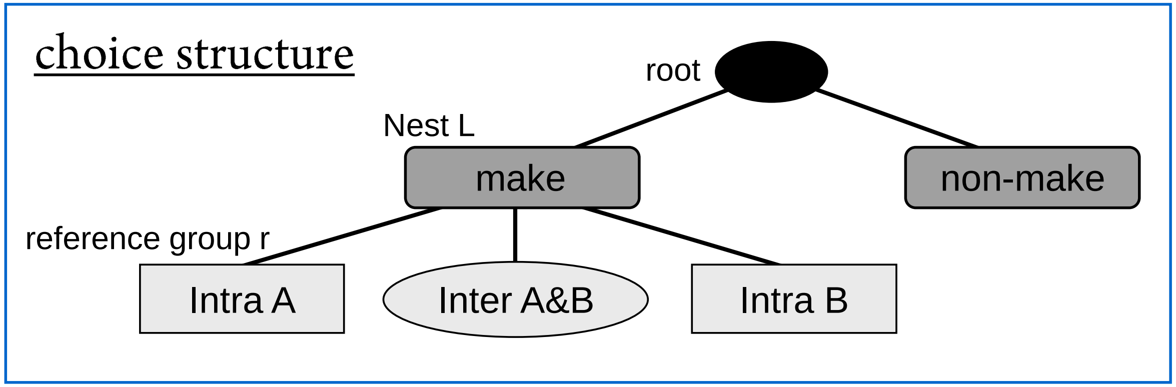
- The field choose "make" and a reference group at the same time slot until "non-make" is chosen
- We can evaluate the reference groups and the number of collective behaviors in the devastated area

<u>Set the time slot</u>



Nested Dynamic Discrete Choice Model

- The Choice structure has a nest: "make/non-make".
- Formulate the dynamic nested logit model (Lorincz (2005))



$$v(r,x_t)=u(r,x_t)+\sigma\varepsilon_t(r)+\varepsilon_t(L)+\beta\sum_{x_{t+1}}\bar{V}(x_{t+1})p(x_{t+1}\mid x_t,j_t) \quad (12)$$

$$P(r\mid t,\theta,\sigma)=P(r\mid L,t,\theta,\sigma)P(L\mid t,\theta,\sigma)$$

$$=\frac{\exp\left((u(r,X_t)+\beta v(r,X_t)/\sigma\right)}{R_L}\frac{\exp(\sigma\ln R_L)}{\sum_{L'}\exp(\sigma\ln R_{L'})} \quad (13)$$

$$R_L=\sum_{r\in L}\exp\left((u(r,X_t)+\beta v(r,X_t)/\sigma\right) \quad (14)$$

$$v(r,X_t)=\sum_{X_{t+1}}\bar{V}(X_{t+1})p(X_{t+1}\mid X_t,r) \quad (15)$$

$$v(r,X_t)=u(r,X_t)+\sigma\varepsilon_t(r)+\varepsilon_t(L)+\beta v(r,X_t) \quad (16)$$

σ : scale parameter ($\sigma\in(0,1)$)

R_L : logsum variable

Estimation Method: NPL

Apply the Nested Fixed Point Algorithm to estimate parameters (Aguirregabiria and Mira (2002))

- NPL is a solution of the dynamic programming problem in the space of conditional choice probabilities
- These two algorithm are iterated until getting choice probabilities that are close enough to the fixed point

The inner algorithm :

It maximizes in Θ a pseudo-likelihood function based on choice probabilities $\Psi_{\Theta}(P)$ where P is an estimate of choice probabilities by the outer algorithm

$$\Theta^{I} = \arg\max_{\Theta} \sum_{t} \ln \Psi_{\Theta}\left(P^{I-1}\right)\left(r_t \mid X_t\right) \tag{17}$$

The outer algorithm :

It is a fixed point algorithm that computes $\Psi_{\Theta}(P)$ at the current parameter estimates to update the estimate of P

$$P^{I} = \Psi_{\Theta^{I}}\left(P^{I-1}\right) \tag{18}$$

I : iteration count, Θ: parameters

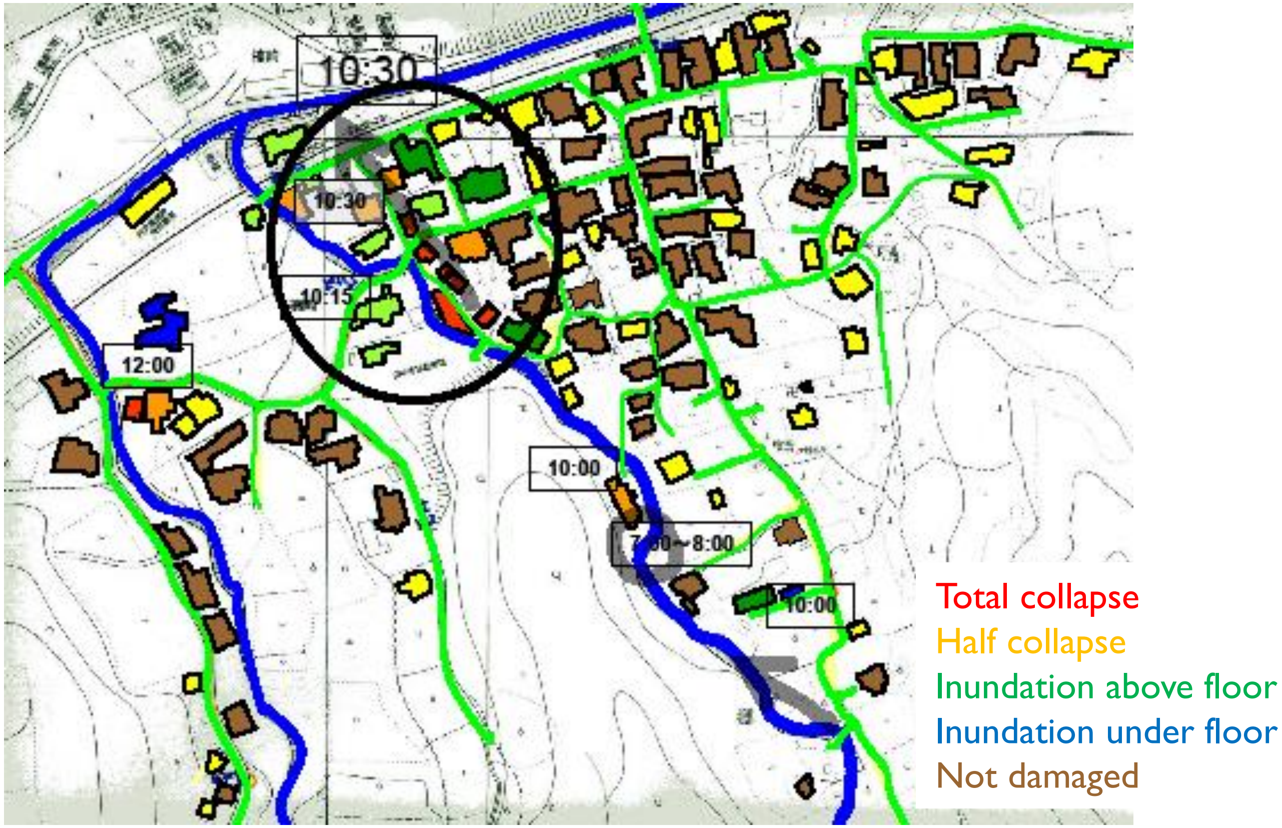
3. Application

The 2004 mudslide disasters in Niihama

- Two disasters were caused by typhoons on August 18 and September 29 in 2004

The August typhoon
- a maximum rainfall of 55mm per hour
- Mudslides left 3 people dead

The September typhoon
- 281mm of rainfall
- Mudslides left 5 people dead



The Survey in Niihama

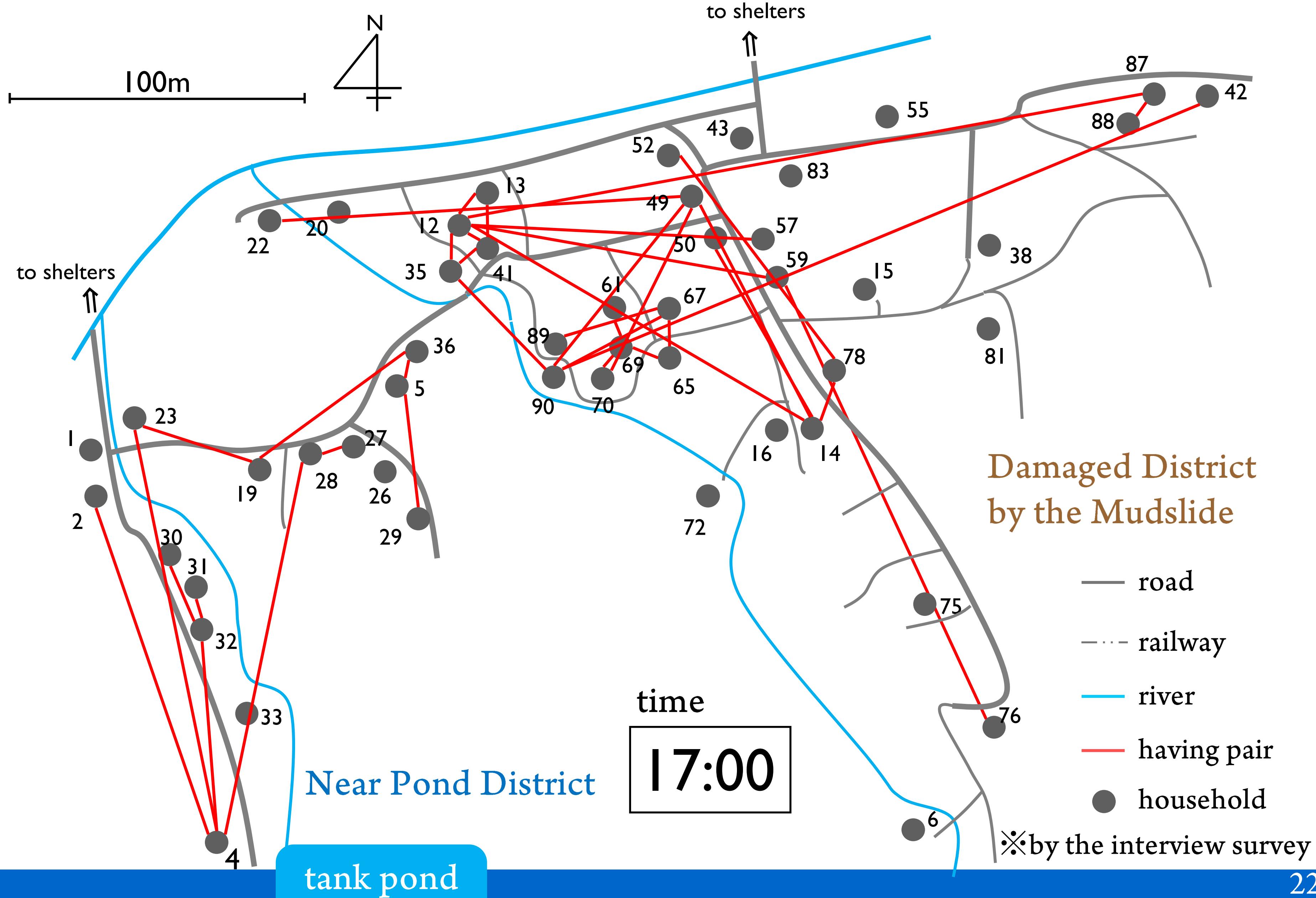
Survey(2004.9-10)

- Surveyed residents' behaviors during these disasters by interviews (Oral communication)
- Interviewed them about their awareness of the danger, risk management behaviors, and collective behaviors
- Collective behaviors include rescuing others, evacuating with others, accommodating evacuees, meeting and exchanging information.

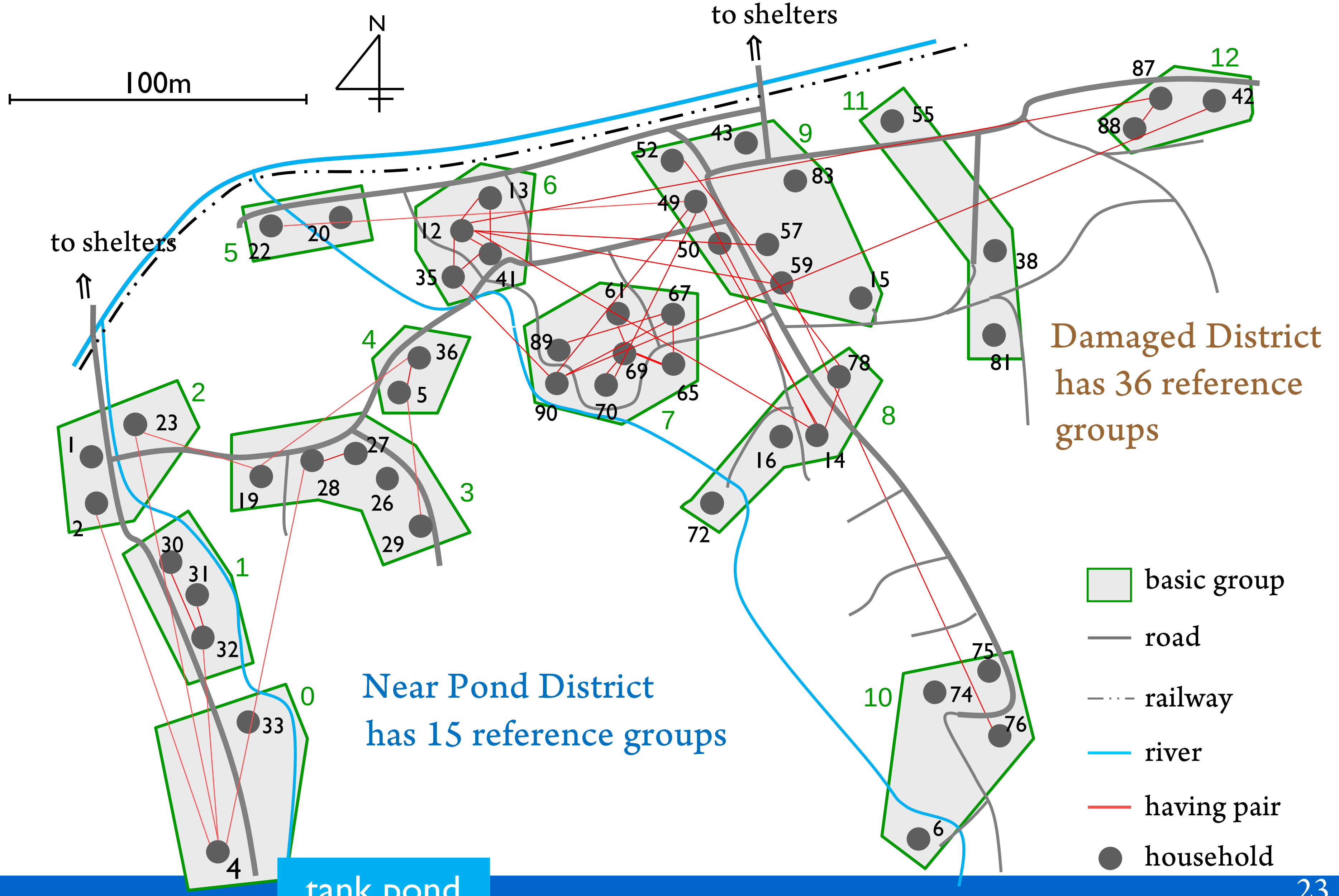
Illustration of Collective Behaviors

- Nodes show households
- Links show collective behaviors between the households

The dynamics of collective behaviors



Divide to Basic Group



Settings of Utilities

$$P(r \mid t,\theta,\sigma) = P(r \mid L,t,\theta,\sigma)P(L \mid t,\theta,\sigma) \quad (13)$$

$$u(r, X_t) = \sum_{r} u'^{r}(r, X_t^{r}) \quad (11)$$

$$u'^{r}(r, X_t^{r}) = \frac{1}{n_r}\sum_{l_{ij}\in r}\left(-(1-\delta_{ij}(t)\alpha)\,|x_i(t)-x_j(t)| - \delta_{ij}(t)c_{ij}^{tr}(t)\right) + f^{cg}(k^{r}(t)) + f^{dj}(k_{\text{inter}}^{r}(t)) \quad (9)$$

$$x_i(t) = \gamma^{dam} x_{dam}^{i}(t) \quad (19)$$

$$c_{ij}^{tr} = \gamma^{dis} x_{dis}^{ij} \quad (20)$$

$$f^{cg}(k^{r}(t)) = \gamma^{\text{cg,inter}} \ln\left(k_{\text{inter}}^{r}(t)+1\right) + \gamma^{\text{cg,intra}} \ln\left(k_{\text{intra}}^{r}(t)+1\right) \quad (21)$$

$$f^{dj}(k_{\text{inter}}^{r}(t)) = \gamma^{dj} \ln\left(k_{\text{intra}}^{r'}(t)+2\right) \qquad \text{r': link to inter group r} \quad (22)$$

$$v(non, X_t) = u^{non}(non, X_t) + \varepsilon_t(L^{non}) + \beta v(non, X_t) \quad (23)$$

$$u^{non}(non, X_t) = u(non, X_t) + \gamma^{rain}\exp(-x_{rain}(t)) \quad (24)$$

γ: parameters

$x_{dam}(t)$: a disaster risk, set by property damage and their rain accumulations

x_{dis}: the distance between their house

x_{rain}: Amount of rain at the time

The transition probability of the number of the collective behaviors use the equation 13.

The other state variables determinably transit along the time

Estimation Result

- We simultaneously estimate parameters of the damaged district and the near pond district
- The time slot is 15minutes
- The gain of inequality averse by collective behavior continue for 3 hours
- The limit of prediction of the future state is 1 hour in advance.

Parameters	result	t-value	result	t-value
γ^{dis}	-0.001	-1.508	-0.001	-3.415**
γ^{dam}	0.235	1.463	-0.003	-0.101
$\gamma^{cg,inter}$	0.430	2.281**	--	--
$\gamma^{cg,intra}$	1.187	1.900*	--	--
γ^{dj}	-0.613	-1.230	--	--
γ^{rain}	1.305	2.260**	1.075	2.906**
α	0.300	--	0.300	--
β	0.500	--	0.500	--
σ	0.156	2.320**	0.109	3.461**
Number of choice		102		102
Log likelihood(0)		-341.53		-341.53
Log likelihood(conv)		-149.28		-201.37
$\bar{\rho}^2$		0.542		0.399

Note: --- = not applicable
** = significant at .05
* = significant at .10

Conclusions

- The spatial reference groups are defined by the norm under disaster situation
- Specify the spatial reference groups which have more collective behaviors
- Model the emergency behaviors with the expectation of future states by the nested dynamic discrete choice
- We demonstrate the synergetic effect

Future works

- Specify the relationship between the collective behaviors and the evacuation timing
- The model of the evacuation timing introduce the spatial reference behaviors

Thank you for your listening.

Mail: urata@bin.t.u-tokyo.ac.jp