"SMART" Cities: Prosocial Multi Criteria Public Housing Assignment Motivated by Neurobehavioral Simulation

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Research Objective

- **Contribution: Develop an interdisciplinary translational model**
  To link neurobehavioral science and multiobjective optimization
- **Plan**:
  - Introduce an economic theory of "*SMART City*" prosocial public housing behavior.
  - Conduct an in-vivo experiment on 4^{th} generation trait-bred male and female Long Evans rats living in alternate housing conditions to obtain, physiological, behavioral and emotional responses when exposed to severe stress via a dose of amphetamine (AMPH).
  - Translate the findings to a human model and obtain per capita social indicator scores (SIS).
  - Parameterize a multiple objective MCDM for prosocial public housing apartment assignment

Architectural Design: “Smart City”

Top 10 “SMART Cities”…?

A city migrates to ‘smart’ status when public policy optimizes resource allocation to support a sustainable prosocial quality of life that effectively promotes economic development by fostering participatory engagement over investments in human and social capital, housing, transport, and communication infrastructure

- Vienna
- Toronto
- Paris
- New York
- London
- Tokyo
- Berlin
- Copenhagen
- Hong Kong
- Barcelona

https://www.fastcodesign.com/1679127/the-top-10-smart-cities-on-the-planet

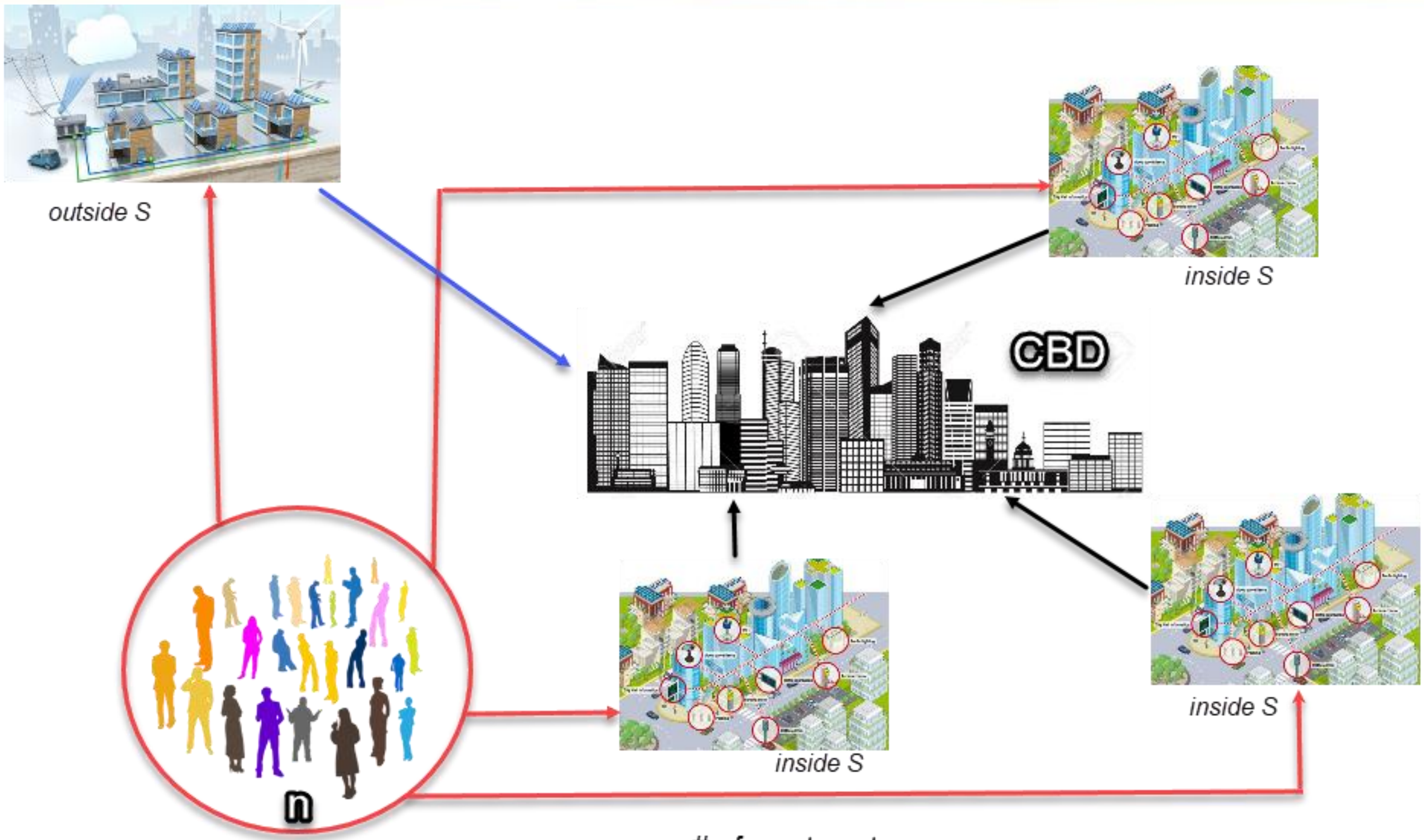
Residential Environment Objectives

- **Residential Objectives**: *To achieve Prosocial behavior*
- **Definition:** *Prosocial behavior is the voluntary action and resulting consequences when individuals help other individuals or groups of individuals.*
- **Examples Include**:
  - sharing,
  - comforting,
  - rescuing,
  - helping.

Antithesis: The 21st century

- antisocial behavior in government subsidized public housing is high
- no sign of abatement.

“ SMART City”: Architectural Assumptions



m = # of apartments
l = # of buildings

Economic Model – Prosocial Public Housing

All eligible persons have an identical preference function:

$$u(s, z, E) = s^{\alpha} z^{1-\alpha} E^{-\beta} \; ; \; 0 < \alpha < 1; \; \beta > 0$$

With a budget constraint:

$$w = z + rs + td$$

Where:

s : utility of a desired increase in housing WRT to z

z: non-housing basket of goods

E: city-wide antisocial behavior

w: wage income

r: rent per unit

t: cost of travel WRT to d

d: distance to CBD (*Central Business District*)

General Equilibrium conditions

- The two equilibrium conditions for the city-wide apartment assignment model are:

$r(w - t\bar{d}, E, v) = r_A$ where r_A is the Ricardian land rent, and

$\int_0^{\bar{x}} \frac{1}{s(w-td,E,v)} dx = n,$ where n fills available apartment units between 0 and $\bar{x}$

$\bar{x} = \frac{n^\gamma[1-r_A^\alpha(r_A+tn)^{-\alpha}]}{t}$ as $n\uparrow$, vacant units $\bar{x}$ are filled

$v = n^\gamma(r_A + tn)^{-\alpha}E^{-\beta}$ the agglomeration effect

Antisocial Behavior Spillover in Public Housing

- Antisocial behavior in building *i* is given by:

$$E_i = e(n_i) + \delta \sum_{j=1}^{m-1} e(n_j)$$

- Where:
  - e: is baseline (reference) antisocial behavior for a building
  - $$\delta = \begin{cases} 0 & \mathit{antisocial\ behavior\ restricted\ to\ a\ building} \\ 0 < \ \delta < 1 & \begin{array}{l} \mathit{degree\ of\ antisocial\ spillovers\ emanating\ from} \\ \mathit{residents\ assigned\ to\ aprtments\ in\ this\ building} \end{array} \\ 1 & \mathit{antisocial\ behavior\ is\ globally\ endemic\ to\ all\ bldgs} \end{cases}$$

Optimal Prosocial Behavior for a Building

- ***Proposition 1:*** $\boldsymbol{\delta = 0}$. *If antisocial behavior is localized and overall building antisocial behavior is measured by how per-capita antisocial behavior changes with a change in the assigned eligible population then, in equilibrium,* ***the building is over- or under-populated***

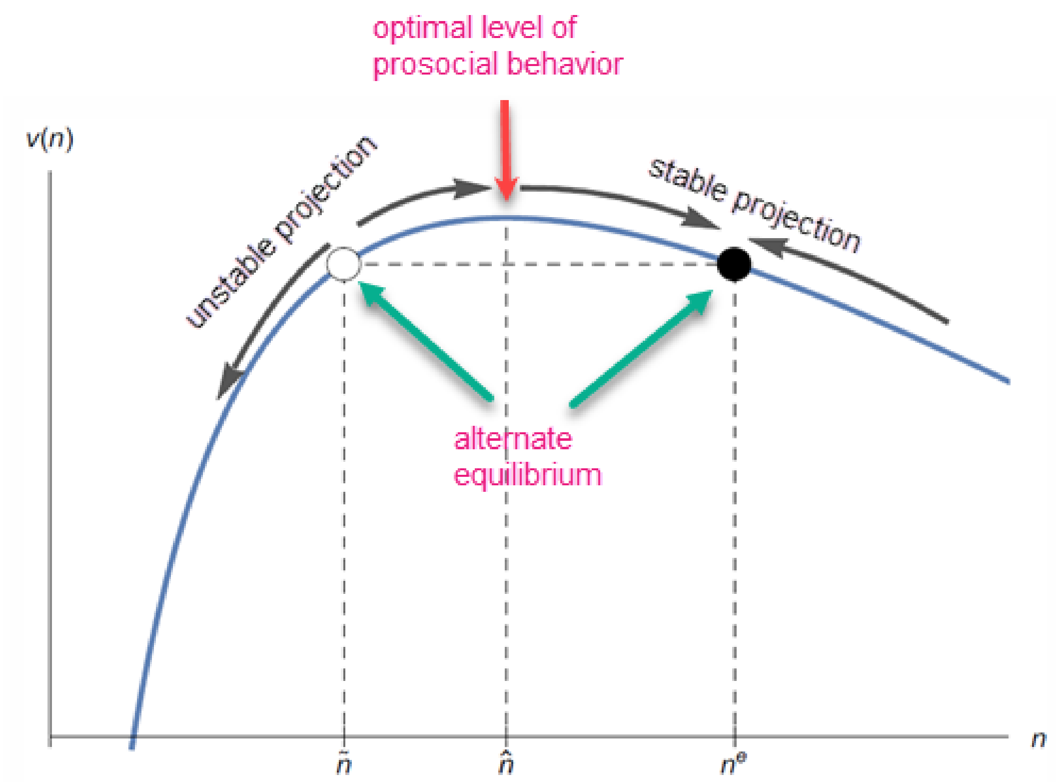
- ***Proposition 2:*** $\boldsymbol{\delta = 1}$. *If eligible resident antisocial behavior increase with n, then city-wide public housing density is beyond established occupancy guidelines or ineligible residents are providing covinous housing. However, if per capita antisocial behavior decreases with a change of n, then* ***building density may either be too small or too large in equilibrium.***

The model provides an optimizing function for city-wide prosocial public housing assignment.

Equilibrium Condition for Prosocial Building

- Antisocial behavior and migration defined in terms of a utility differential:

$$v(n_i) - v(n_j) = v(n_i)\, e(n_i\,)^{-\beta} - \hat{v}(n_j) e(n_j\,)^{-\beta}$$

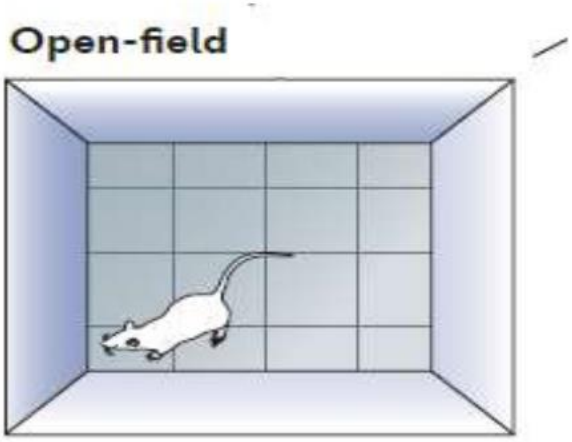


The New Frontier for Machine Translation: The Neural Frontier

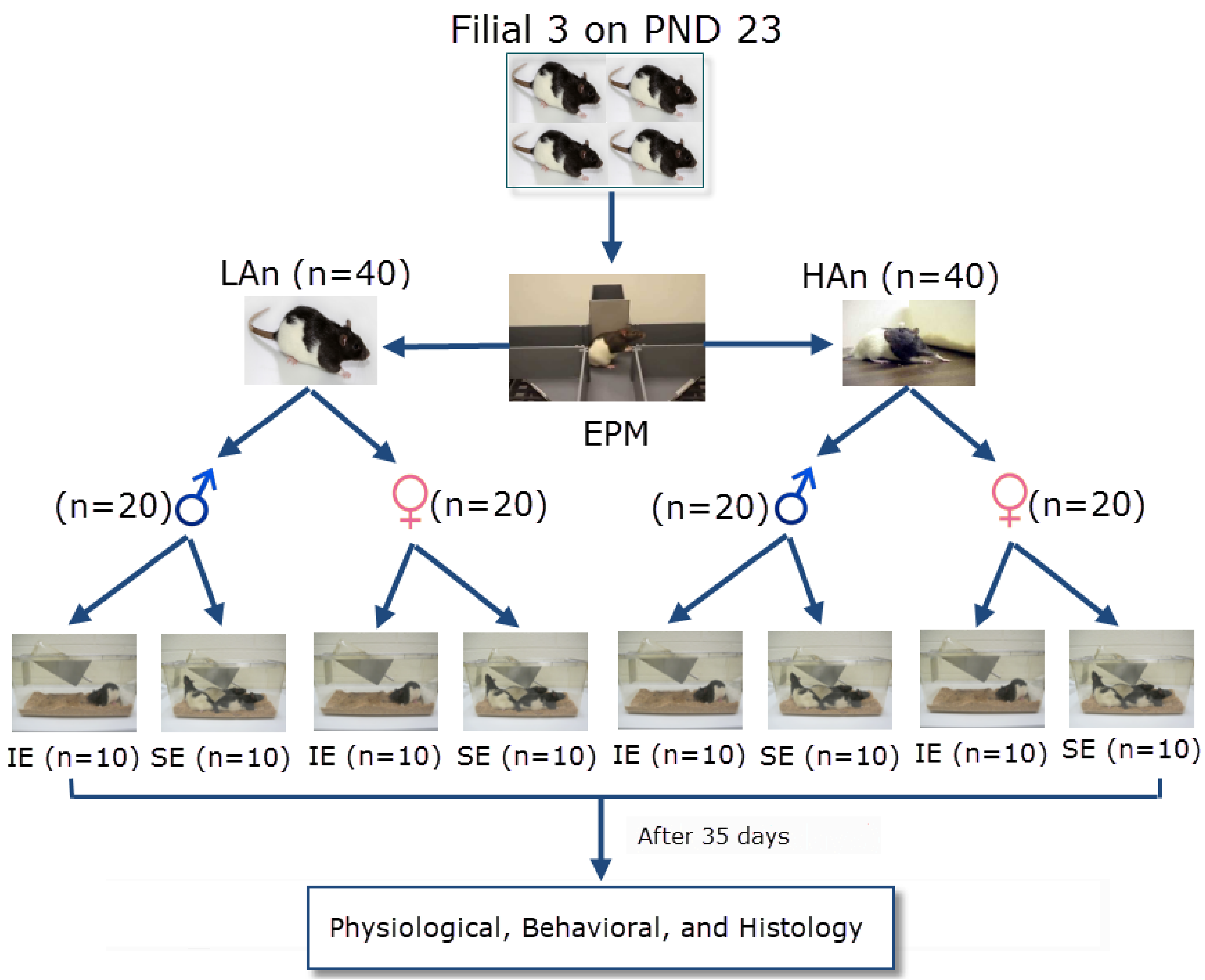
https://www.gala-global.org/conference/annual-conference-2017-amsterdam/new-frontier-machine-translation-neural-frontier

Elevated Plus Maze

- **Open-field Test**



Animal Husbandry



Physiological and Behavioral Analysis

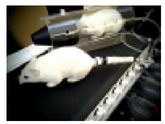
Physiological Testing
(avg n=5 per group)

Temperature

Airpuff

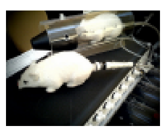
Temperature

1 pre and post measurement



BP

Airpuff



BP

15 pre and post measurements in 1min interval

Behavioral Testing
(n=10 per group)

EPM

Measured time spent in Open and Closed Arms, and # of Entries

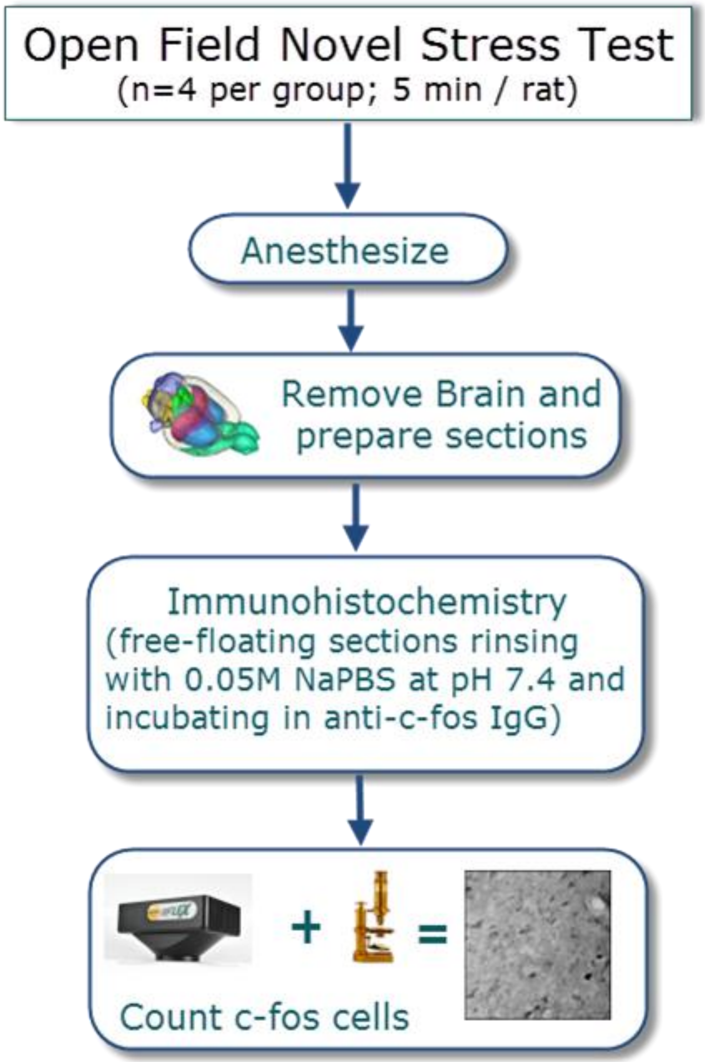
LMA - 30 mins

0.5mg/kg IP AMPH

LMA - 60 mins

Measured Horizontal Distance Traveled and Vertical Rearing in 5 min interval pre- and post- AMPH

Histology



Expression of ***c-fos*** by individual neurons can be used as a marker of cell activation in neuroendocrine systems. ***c-fos*** cells were counted in the left- and right- side of the following seven (7) brain regions:

Brain Region	**Implicated by:**
Periaqueductal Gray (PAG)	Stimulant drugs and social stress
Amygdala (Amy)	Fear / Anxiety (Flight or Fight)
Ventromedial hypothalmus (VMH)	Fear / Anxiety (Defensive Emotion)
Cingulate gyrus 1 (Cg1) & Cingulate gyrus 2 (Cg2)	Cognitive control of emotions
Nucleus accumbens core (NAc(c)) & shell (NAc(sh))	Fear / Reward

Data Analysis

- Analytical methods use the data from the Open Field Novel Stress Test (OFST).
- The OFST experimental design:
  - **Fixed inputs (predictors)** are: SEX, TRAIT, ENVIRONMENT
  - **Response variables (targets or dependents)** are: average c-*fos* level from left- and right- side of each of the 7 brain regions.
  - # of observations = 32
- Analytical Procedure
  - Mean, Standard deviation, and intercorrelations
  - Exploratory factor analysis (PCA → Varimax)
  - Comparative analytics: 7 MANOVA models and 7 MRANN models
  - MRANN – multivariate radial basis function artificial neural network

Descriptive Statistics – Mean & STD

	PagL	PagR	AmyL	AmyR	Cg1L	Cg1R	Cg2L	Cg2R	NAc(c)L	NAc(c)R	NAc(Sh)L	NAc(Sh)R	VMHL	VMHR
Female														
LAn IE	11.75	13.33	9.42	10.17	9.75	9.08	9.75	9.34	9.75	9.08	9.75	9.34	9.08	6.00
	1.29	4.12	7.65	8.31	3.01	1.66	3.89	5.10	3.01	1.66	3.89	5.10	6.38	2.45
LAn SE	16.42	22.00	8.33	11.00	12.59	10.67	11.59	10.42	12.59	10.67	10.42	10.42	10.75	5.75
	4.14	5.59	6.70	8.04	2.36	2.60	2.46	3.36	2.36	2.60	3.36	3.36	8.21	4.92
HAn IE	13.42	15.00	12.42	11.08	7.92	6.83	7.25	8.00	7.92	6.83	7.25	8.00	14.09	15.25
	8.33	9.76	7.55	8.85	1.69	2.73	1.97	3.23	1.69	2.73	1.97	3.23	2.53	4.03
HAn SE	14.33	17.58	8.58	7.50	10.75	7.92	7.08	13.17	10.75	7.92	7.08	13.17	7.58	8.50
	3.89	5.07	2.13	2.12	6.60	3.63	1.20	**15.59**	6.60	3.63	1.20	**15.59**	3.83	3.87
Male														
LAn IE	14.83	15.92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	10.00	11.08
	7.04	4.58	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.66	7.88
LAn SE	10.67	13.17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.17	8.25
	0.86	3.13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	**10.46**	1.60
HAn IE	10.25	9.50	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	8.34	9.08
	3.86	4.24	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	5.13	2.47
HAn SE	12.08	15.92	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.58	8.67
	2.42	6.79	5.85	6.25	7.33	5.31	7.38	**19.06**	**18.63**	**15.44**	**15.34**	**17.94**	2.76	1.25

Note: Higher the mean value deeper the red color; lower the mean value darker the green color; Standard deviations are presented as unshaded values; bold = STD > 10.0

Findings (c-*fos* for Female Group):

a) HAn IE group show higher emotional fear (panic) (Amy & VMH);

b) LAn SE group show high mean c-*fos* levels in ALL brain regions

Descriptive Statistics – Mean & STD

	PagL	PagR											VMHL	VMHR
Female														
LAn IE	11.75	[illegible]											9.08	6.00
	1.29	[illegible]											6.38	2.45
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LAn IE	14.83	15.92	17.17	20.58	24.00	12.59	10.25	13.58	6.75	11.42	10.17	8.75	10.00	11.08
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LAn SE	10.67	13.17	15.00	14.25	11.33	7.67	8.58	7.75	8.33	9.42	8.42	9.50	12.17	8.25
	0.86	3.13	6.81	4.58	4.74	1.96	2.64	2.75	0.67	3.01	2.54	4.99	**10.46**	1.60
HAn IE	10.25	9.50	19.83	18.17	11.17	12.92	11.25	12.58	7.67	10.42	7.33	11.34	8.34	9.08
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Note: Higher the mean value deeper the red color; lower the mean value darker the green color; Standard deviations are presented as unshaded values; bold = STD > 10.0

Findings (Male Group):

a) HAn SE group shows an across the board effect of increased stress (unlike the Female group)

b) HAn and LAn IE groups show a considerable reaction to fear/anxiety (aggression) and emotion (Amy, Cg1 & Cg2)

Exploratory Factor Analysis with Varimax Rotation

	Fear / Reward Emotional Circuit	Fear / Anxiety Emotional Circuit	Fear / Anxiety Drug and Stress Induced	Fear / Anxiety Escape Circuit
NAc(c)-R	0.919			
NAc(c)-L	0.901			
Cg2-R	0.893			
NAc(S				
NAc(S				
Cg2-L				
Cg1-R				
Amy-L				
Amy-R		0.737		
Cg1-L		0.687		
PAG-R			0.929	
PAG-L			0.911	
VMH-R				0.872
VMH-L				0.858
CumVar %	33.83%	51.01%	63.98%	76.08%

Scale: Red-Yellow-Green = High to low contribution

- Taken together the 7 brain regions explain 76% of the variation in the c-*fos* levels.
- As expected Left- and Right- brain regions show common variance.

Can we identify neurobehavioral factors that explain the complex interrelationships among the c-*fos* levels in the seven brain regions of stressed rats?

Effect of Sex, Trait, Envir

Main effect of SEX in Amy &Cg1 – regions implicated by fear due to anxiety and cognitive control of emotions

	PAG	Amy	Cg1	Cg2	NAc(c)	NAc(sh)	VMH
	NO SIG			NO SIG		NO SIG	
Sex		0.682, 5.371	0.765, 3.530				
Trait							0.726, 4.334
Environment					0.776, 3.310		
Sex*Trait			0.729, 4.272				0.796, 2.955
Sex*Environment			0.810, 2.704				
Trait*Environment							
Sex*Trait*Environment							

NOTE: 1st row=Wilks' Lambda; 2nd row *f-value*. Gree

Main effect of TRAIT in VMH – region associated with fear/anxiety and escape

LAn Males showed higher c-*fos* levels than HAn Males; Indicating better control of emotions.

Multivariate Radial Basis Function ANN (MRANN)

$$Y_{(Nxp)} = f\left(X_{(Nxq)}\right) = W_{(Nxm)}H_{(mxp)} + \varepsilon_{(Nxp)}$$

Where:

Y, N, p, ε = as stated in MANOVA model

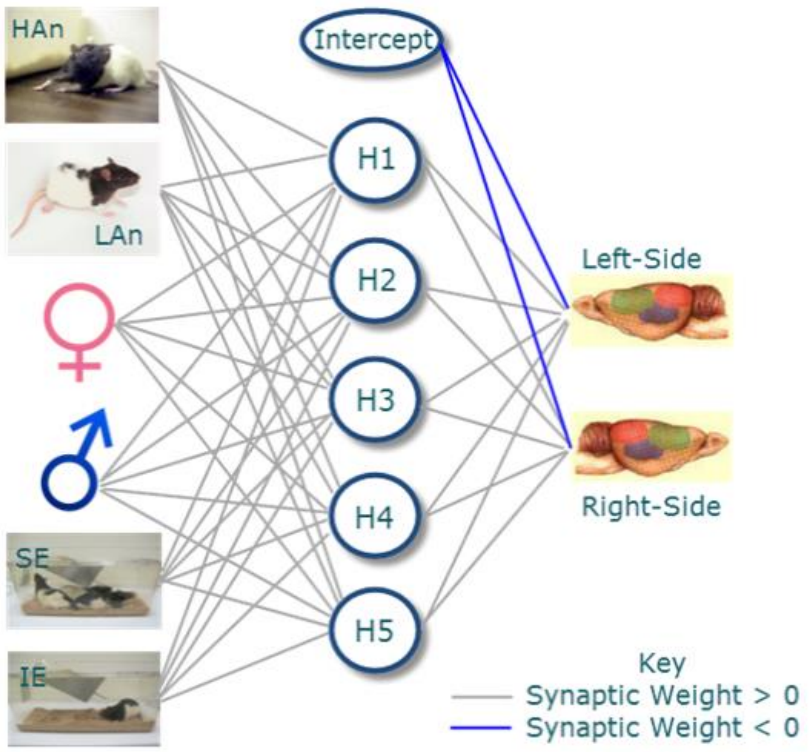
X = input matrix

W = weight matrix

H = hidden units matrix

q = #of inputs (3; 2 levels each)

m = #of hidden units (varies)



Example: PAG Network

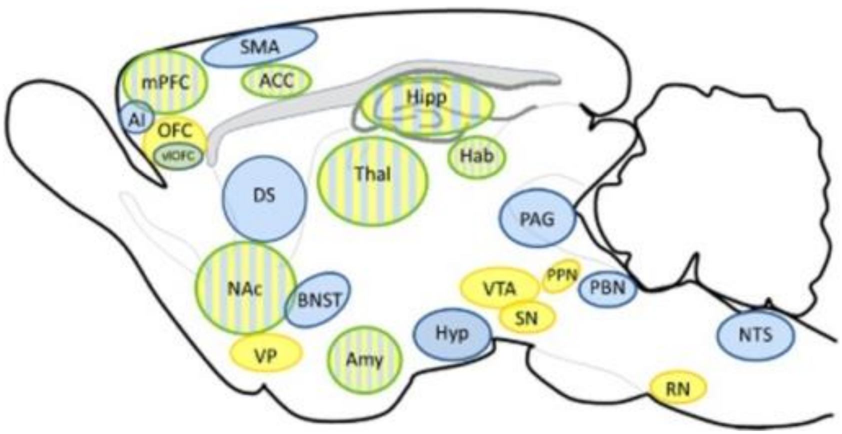
MRANN: Importance of Predictors (Normalized)

Table 6: RBF Importance of Variables (Normalized)

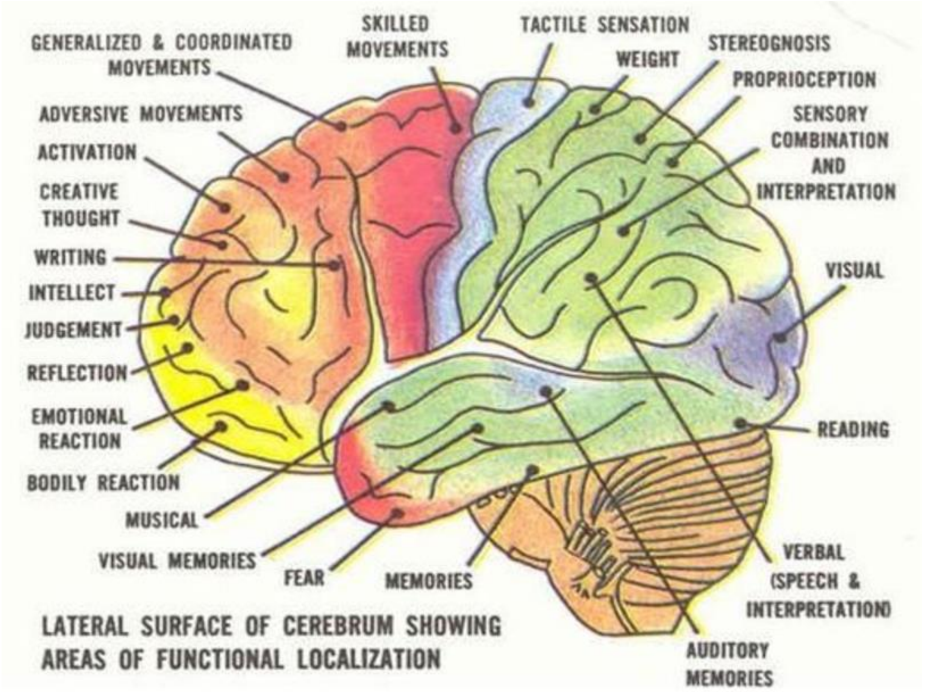
	PAG	Amy	Cg1	Cg2	NAc(c)	NAc(sh)	VMH
Sex	100.0	100.0	100.0	100.0	84.0	29.3	76.2
Trait	47.9	22.8	63.0	88.4	71.8	100.0	96.4
Environment	96.7	8.6	47.5	99.5	100.0	44.8	100.0

- Primary Contributors in the explanation of variation in c-*fos* levels are:
  - SEX and ENVIRONMENT in regions implicated by:
    - Stimulant drugs and social stress (PAG)
    - Fear / Anxiety (Defensive Emotion) (Amy & VMH)
    - Cognitive control of emotions (Cg1 or Cg2)
    - Fear / Reward (NAc(c))
  - TRAIT in regions implicated by:
    - Fear / reward (NAc(sh))
    - Fear / anxiety (VMH)

The Neural Translational Model



Rat Brain



Human Brain

Translational Science

Animal Model		Human Model
Subject: Rats	≡	Subject: Human
Trait • HAn • LAn	≡	Psychological Factors • Prone to Hypertension, Anxiety, Panic, Stress, etc. • More in control of Emotion
Sex • Male • Female	≡	Sex • Male • Female
Environment • Isolated • Social	≡	Housing / Building • Area *Outside S* • Area *Inside S*
Behavior • EPM • LMA	≡	Migration • Entryways • Courtyards / playgrounds
Physiological • BP and Temperature		Physiological Markers • BP, Temperature, Pulse, etc. measured via ECG or PPG
Open field novel stress test /w AMPH	≡	An anxiety / stress inducing scenario to measure emotional response such as the Stroop Test, Stress Scale Questionnaire, Reaction Time Test, etc.

Formulating the SIS Index

- The per capita gender-differentiated SIS is calculated as a simple average across the independent factor score vectors obtained from EFA. Factor scores are computed using Thomson (1951) Maximum Validity (or regression) method.
- Thus the formulation of SIS is stated as:

$$SIS_{i,n}^{G} = \frac{\sum_{j=1}^{C} f_{i,j}}{C},$$

- Where:
  - G is the gender indicator
  - f_i is the score of the *i-th* individual on the factor
  - C is the number of factors
- Following this approach, the SIS per capita metric effectively captures emotion and consequentialism in multicriteria decision making

MCDM & Optimal Prosocial Housing Assignment

- **GOAL:** Design an equilibrium aware prosocial combinatorial **m**ultiple **c**riteria **d**ecision-making **m**odel (MCDM) to optimize the assignment of public sector apartments.
- We propose a mixed-integer nonlinear goal programming (MINLGP) method of Dash & Kajiji (2014) to solve the multiple objective problem:

$$MINLGP = Min\ Z = \left[P_1(h^-, h^+),\ P_2(h^-, h^+),\ \ldots,\ P_L(h^-, h^+) \right]$$

$$S.T.\quad Ax + Bf + h^- - h^+ = b$$

$$x, f, h^-, h^+ \geq 0\ ,\ f \in Z^F,\ \text{and},\ x \in \Re^{l-F}$$

Where k, the number of goal constraints is such that $A \in \Re^{k \times l}$, $B \in Z^{k \times F}$, $b \in \Re^k$, and Z quantifies the attainment of L hierarchical levels such that $P_1(h^-, h^+) > P_2(h^-, h^+) > \ldots \geq P_L(h^-, h^+)$. The specification b is the k-component vector of goal targets and h^- and h^+ are k-component column vectors that capture goal under- and over-achievement, respectively. The optimal solution to the convex MINLGP is x^*, which satisfies all hierarchical goals as much as possible.

MOAP Constraints

- We add the following two goal constraints to establish a multiple objective assignment problem (MOAP).

$$\sum_{i=1}^{n} x_{i,j} + h^- - h^+ = 1 \qquad for\ all\ j = 1, 2, \dots, m$$

$$\sum_{j=1}^{m} x_{i,j} + h^- - h^+ = 1 \qquad for\ all\ i = 1, 2, \dots, n$$

$$x_{i,j} \in \{0,1\} \ \ \forall \text{ i and j}$$

- Assure maximal coverage for eligible residents by assigning each to an available apartment: Boundary Conditions, specifically ẍ.

Prosocial Housing Assignment Goal Constraints

- **Prosocial Goal Constraints:**
- $\sum_{i \in I} \sum_{j \epsilon m_i} SIS_{i,j}\, x_{i,j} - h^{+} = 0$ — Minimize community wide SIS
- $\sum_{i \in I} HAn\left(x_{i,OS}^{male}\right) + h^{-} - h^{+} = y_i$ — Assignment HAn males to OS
- $\sum_{i \in I} HAn\left(x_{i,IS}^{female}\right) + h^{-} - h^{+} = y_i$ — Assignment HAn females to IS
- $\sum_{i \in I} LAn\left(x_{i,IS}^{male}\right) + h^{-} - h^{+} = y_i$
- $\sum_{i \in I} LAn\left(x_{i,OS}^{female}\right) + h^{-} - h^{+} = y_i$
- $\sum_{i \in I} AMPH\left(x_{i,IS}^{male}\right) + h^{-} - h^{+} = y_i$ — Assign Residents with substance abuse
- $\sum_{i \in I} AMPH\left(x_{i,IS}^{female}\right) + h^{-} - h^{+} = y_i$ — *inside S*
- $\sum_{i \in I} y_i m_{i,IS} \leq m_{IS}$ — Limit on total assigned apartments
- $\sum_{i \in I} y_i m_{i,OS} \leq m_{OS}$
- $\sum_{i \in I} y_i m_{i,IS} + \sum_{j \epsilon I} y_j m_{j,OS} \leq m$

MCDM & Optimal Prosocial Housing Assignment

$$Min\ \ Z = \left\{P_1\left[h_{16}^{+}\right], P_2\left[h_{20}^{+}\right], P_3\left[h_{20}^{-} + 2h_{21}^{-}\right]\right\}$$

Max SIS

Min LAn females to *Outside S*

Substance abuse males *Inside S*

Twice as important to assign substance abuse females *Inside S*

Conclusion & Future Research

- Animal studies indicate that gender differences exist due to anxiety, acute stress, and rearing environments. Their reaction is also tempered by the way they process fear and reward situations.
- The prosocial MOAP specification is capable of incorporating any number of explicit functional relationships such as:
  - **To mitigate and control goal deviation in the management of the emotional response to fear among all residents.**
  - Because male rodents showed greater evidence of stress when living in social housing, for **families where the head of household is male we include a goal to minimize the under-achievement of assigning these families to *outside S***.
- Future research design now contemplates the use of simulation methods to create a sub-population of eligible residents with levels of anxiety trait who are seeking subsidized housing placement in a hypothetical "SMART" city.
- The housing administrators of this "SMART city" will use MOAP to obtain a prosocial equilibrium assignment.

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QUESTIONS???

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