

Modeling Oxytocin Induced Neurorobotic Trust and Intent Recognition in Human-Robot Interaction

Sridhar R. Anumandla, Laurence C. Jayet Bray, Corey M. Thibeault, Roger V. Hoang,
Sergiu M. Dascalu, Frederick C. Harris, Jr., and Philip H. Goodman

Abstract — Recent human pharmacological fMRI studies suggest that oxytocin (OT) is a centrally-acting neurotransmitter important in the development and expression of trusting relationships in men and women. OT administration in humans was shown to increase trust, acceptance of social risk, memory of faces, and inference of the emotional state of others, in part by directly inhibiting the amygdala. However, the cerebral microcircuitry underlying this mechanism is still unclear. Here, we propose a spiking integrate-and-fire neuronal model of several key interacting brain regions affected by OT neurophysiology during social trust behavior. As a social behavior scenario, we embodied the brain simulator in a behaving virtual humanoid neurorobot, which interacted with a human via a camera. At the physiological level, the amygdala tonic firing was modeled using our recurrent asynchronous irregular nonlinear (RAIN) network architecture. OT cells were modeled with triple apical dendrites characteristic of their structure in the paraventricular nucleus of the hypothalamus. Our architecture demonstrated the success of our system in learning trust by discriminating concordant from discordant movements of a human actor. This led to a cooperative versus protective behavior by the neurorobot after being challenged by a new intent.

Index Terms: Human-robot interface, learning, neurorobotic trust and intent, social robotics.

Manuscript received January 21, 2011. This work was supported in part by the U.S. Office of Naval Research under Grant (N000140110014 and DURIP N000140510525).

Sridhar R. Anumandla is with the Department of Computer Science and Engineering, University of Nevada, Reno, NV 89557 USA (e-mail: sridhar.anumandla@gmail.com).

Laurence C. Jayet Bray is with the Department of Computer Science and Engineering, University of Nevada, Reno, NV 89557 USA (e-mail: ljayet@gmail.com).

Corey Thibeault is with the Department of Computer Science and Engineering and Department of Electrical and Biomedical Engineering, University of Nevada, Reno, NV 89557 USA (e-mail: corey@cmthibeault.com).

Frederick C. Harris, Jr. is with the Department of Computer Science and Engineering, University of Nevada, Reno, NV 89557 USA (e-mail: fred.harris@cse.unr.edu).

I. INTRODUCTION

THE field of social robotics has been focused on better understanding the important dynamics of human emotion [1-3]. For many decades, intelligent systems have tried to replace a human mind in planning, learning new functions, and making decisions, but several traits, such as social skills have been hard to replicate. For this reason, many investigators are now attempting to incorporate realistic neuromorphic properties into machine learning systems. An overarching societal goal of this research is to incorporate the resultant knowledge about intelligence into machine learning systems.

Imitation is a recurrent mechanism in human behavior from early ages to adulthoods, and it is associated to cooperation and trust [4]. It has been observed that during social interactions between two or more people, humans unconsciously and unintentionally learn to imitate trustworthy behaviors. Paukner *et al.* (2009) showed that Capuchin monkeys display affiliation towards humans who imitate and spend more time by interacting with them [5]. Intent recognition has been a wide research area in robotics since it is very important for developing social robots that can cooperate with humans in performing tasks [6, 7].

We speculate that profound knowledge of hypothalamic oxytocin and amygdala is essential in simulating complex neuromorphic brain models of social cognition that involve short term memory [8, 9], trustworthiness [10-12] and suppression of fear [13, 14]. Responsible for developing trust in humans, oxytocin was found as the major peptide involved [10-12, 15, 16]. It plays a key role in modulating complex emotional and social behaviors, social recognition and aggression [17-22]. An increase in the level of oxytocin would suppress the activity in the amygdala [13, 14, 23], which is present in the medial temporal lobe and is responsible for social cognition and fear in mammals [24-26], thereby establishing trust.

Based on these observations, our goal was to model a neuromorphic brain and implement it on a virtual neurorobot, which could learn to trust a human if its actions were imitated by that person. On the contrary, if the person did not imitate the virtual neurorobot actions then trust would not be established. The major parts of the human brain that needed to be modeled in order for the virtual neurorobot to trust or distrust a person were the visual cortex, parietal cortex, inferotemporal cortex, hypothalamus, and amygdala, corresponding to the concordant or discordant motions.

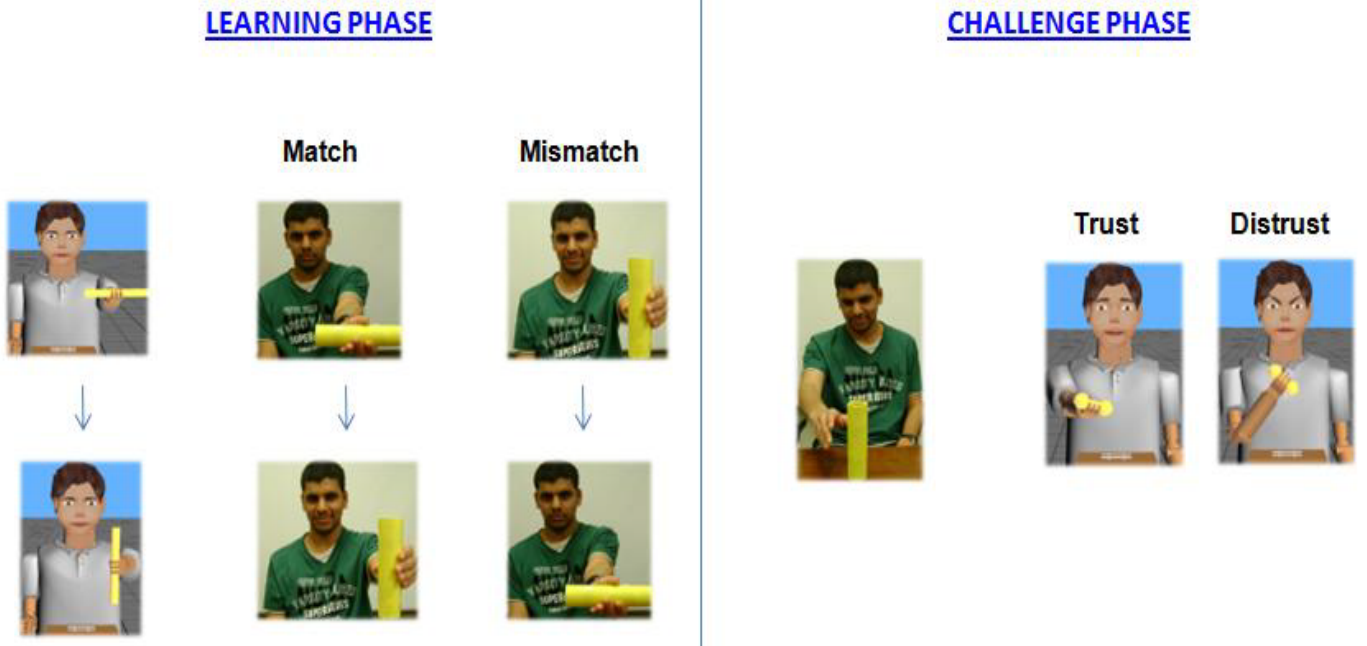


Fig. 1: Behavioral Paradigm of the Instinctual Trust-the-Intent Scenario. During the learning phase (left), the human matched or mismatched the virtual neurorobot’s horizontal or vertical motions. During the challenge phase (right), the human reached for an object to test the trust instinct of the neurorobot.

Here, we utilized the VNR system developed in our laboratory [3, 27] to rapidly forward engineer a robotic system that can interact with humans. The computational architecture included integrate-and-fire, conductance-based synaptic cell representations of 15 brain regions, including hypothalamic oxytocin cells, amygdala, and neocortex (visual, parietal, and inferotemporal associations) using our neocortical simulator (NCS) [28].

II. MATERIALS AND METHODS

A. Behavioral Scenario

In our experiments, a virtual humanoid neurorobot stood behind a table holding a yellow rod, and the virtual environment projected on a large screen. A similar setup was available in our laboratory where a person sat in front of a camera placed on a table and held a rod similar to the one present in the virtual environment. A dumbbell was placed on the table and a similar object was loaded into the virtual environment at a later stage of the experiment.

The experiment was divided into two phases, which were integrated into a single setup. During the learning phase, the virtual neurorobot was configured to perform 5 second sequences of vertical or horizontal motions, for a total duration of 20 seconds. Every motion was captured in the top 50% of the field of view (FOV) of the camera. At the end of this phase, if the human mimicked the actions (concordant motion) of the virtual neurorobot then the neuromorphic brain was trained sufficiently enough to trust the human. On the other hand, if the human did the opposite actions (discordant motion) from the virtual neurorobot trust was not established. During the challenge phase, if the human reached for the dumbbell a similar action was loaded

into the virtual environment dynamically. This reaching motion was captured in the bottom 50% of FOV of the camera. If trust was established the virtual neurorobot preemptively handed over the object to the trusted person by happily nodding its head. However, if the person was not trusted the virtual neurorobot then retracted the dumbbell towards itself and shook its head expressing anger. This behavioral scenario is illustrated in Fig. 1.

B. Robotic System

The robotic system for this project was designed around a number of components unique to NCS and the VNR paradigm [24]. The neural simulation was executed on a remote computing cluster and was networked to the other system components using the Brain Communication Server (BCS) [26], a publish-subscribe server developed specifically for integration with NCS. The closed loop robotic system is diagrammed in Fig. 2 and the other major components are described below.

NCSTools

NCSTools is a C++ based software system that provides a number of mechanisms for communicating in real-time with a running NCS simulation [27]. NCSTools accepts plain text strings from clients connected through the built-in socket server. Through a custom configuration file, users can then assign these strings to input stimulus to, or simulation controls of, a running NCS instance. Similarly, NCSTools can be configured to process simulation reports in a number of different ways. The results of which can be sent to connected clients through the server interface. With this designers of remote tools can interface with neural-

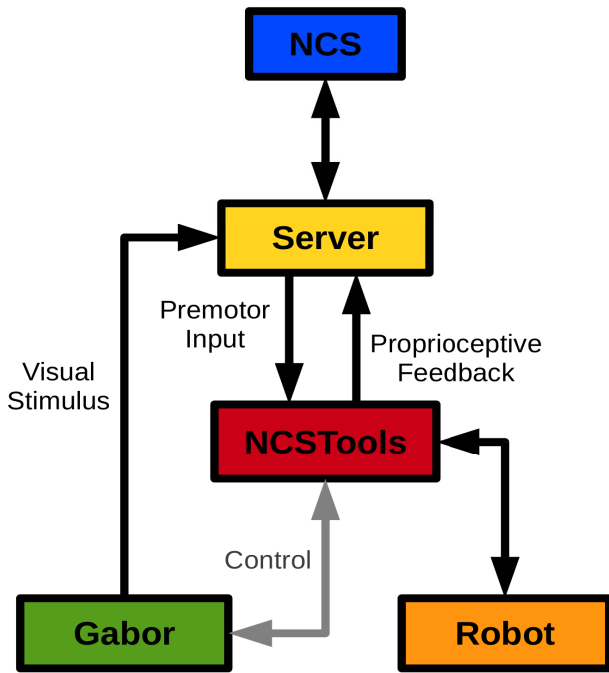


Fig. 2: Robotic System Configuration. Closed loop robotic system with its five major components.

simulations in a way that abstracts them from the details of the model. Ultimately, allowing reuse of code without modification for different models; only the NCSTools configuration needs to be changed.

The NCSTools server monitors the robotic avatar and creates the appropriate stimulus for proprioceptive feedback. Similarly, NCSTools receives spiking information from the premotor region of the neural simulation. This activity is monitored and when the configured threshold is reached the appropriate command is sent to the robotic avatar, initiating the appropriate motion.

Robotic Avatar

The robotic interface was constructed using Webots 5 (Cyberotics, Lausanne, Switzerland). The motions were programmed in C++ using the provided interfaces and the communication was accomplished using the NCSTools C++ client.

Gabor Filter

The Gabor filter is considered one of the better representations of mammalian visual receptive field profiles [29]. Often used for edge detection, the Gabor filter can spatially filter an image by frequency and orientation [30]. Although Gabor filters provide a good approximation of human visual information, the computational cost is often too high for real-time applications. To reduce the processing time, a GPU based Gabor filter application was developed.

The Gabor processing application is designed around NVidia's CUDA programming environment. CUDA provides mechanisms for GPU algorithm development with

an emphasis on high-performance applications. Processing begins with the capture of a 320x240 pixel image at a frequency that is determined by the user during the application configuration. A 128x128 pixel area of interest is then selected and the grayscale information is extracted. The area of interest is differenced with the previously captured image. This differencing provides an immediate representation of the motion between the two images. The differenced image is then padded with zeros to 256x256 pixels and a fast Fourier transform (FFT) is computed. The frequency space image is processed with a pre-computed complex Gabor kernel and the inverse FFT is computed. The original 128x128 pixel area is extracted and segmented into a user-defined number of regions. Each region is normalized in way similar to how it would be presented on screen. The normalized values are averaged for each region and sent directly to the running NCS brain simulation as a stimulus using the network interface.

C. Neuromorphic Computational Architecture

The computational neuromorphic brain architecture consisted of the visual, parietal, inferotemporal, and pre-motor cortices, along with the hypothalamus and amygdala limbic systems. The visual, parietal, and inferotemporal cortices served as input to the hypothalamus. The visual cortex received input from the external camera, which captured human motions; the parietal cortex received input from the neurorobot based on its motions; and the inferotemporal cortex was stimulated by a monotonic current. A recurrent asynchronous irregular non-linear (RAIN) network [31-33] was introduced in the amygdala to emulate a background activity. This network used a 4:1 ratio of excitatory and inhibitory cells with a 3% connectivity, which resulted in irregular firing patterns with periods of higher firing rates separated by generally longer periods of low inactivity as observed in the human brain [34].

A monotonic stimulus was injected into the parietal trust column, which was inhibited by the amygdala. But, since there was no suppression of the amygdala activity by the hypothalamus for the discordant motion the distrust column won during the reach action. However, for the concordant motion, trust was successfully recognized since the hypothalamus suppressed the amygdala and there was more activity in the parietal trust column compared to the distrust column. This phenomenon was reinforced by using synaptic time-dependent plasticity (STDP) in the hypothalamic synapses. Whether the parietal trust or distrust column won, a corresponding pre-motor column was triggered. Consequently, a motor command was sent to the brainstem [35], which in turn was directed to the neurorobot. The connectivity of computational neuromorphic brain architecture is illustrated in Fig. 3 and summarized in Table I.

Table I: Description and Analysis of the Computational Neuromorphic Brain

A		Model Summary
Populations	Inferotemporal cortex (IT), visual cortex (VC), parietal cortex (PR), premotor cortex (PM), hypothalamus (HYPOTH), and amygdala (AMY)	
Neuron Model	Leaky integrate-and-fire, fixed threshold, refractory time	
Plasticity	STDP	
Synapse Model	Conductance-based	
Measurements	Membrane Potential	
B		Extrinsic Connectivity
Type	Description	
VC/PR/IT - HYPOTH	Visual, parietal, and inferotemporal input to the hypothalamus	
VC - PR	After the visual cortex receives input from the activity is projected to the parietal cortex	
HYPOTH - AMY	The hypothalamus activates or suppresses the amygdala depending on instinctual trust or distrust	
AMY - PR	If the amygdala is not suppressed by the hypothalamus, information is sent to the parietal cortex	
PR - PM	The parietal cortex is directly connected to the premotor cortex	
C		Input
Visual Stimuli	The visual cortex receives input from the external camera through the Gabor filter which captures human motions	
Proprioceptive	The parietal cortex receives input from the neurorobot based on its motions	
Monotonic	The inferotemporal cortex receives monotonic stimuli	

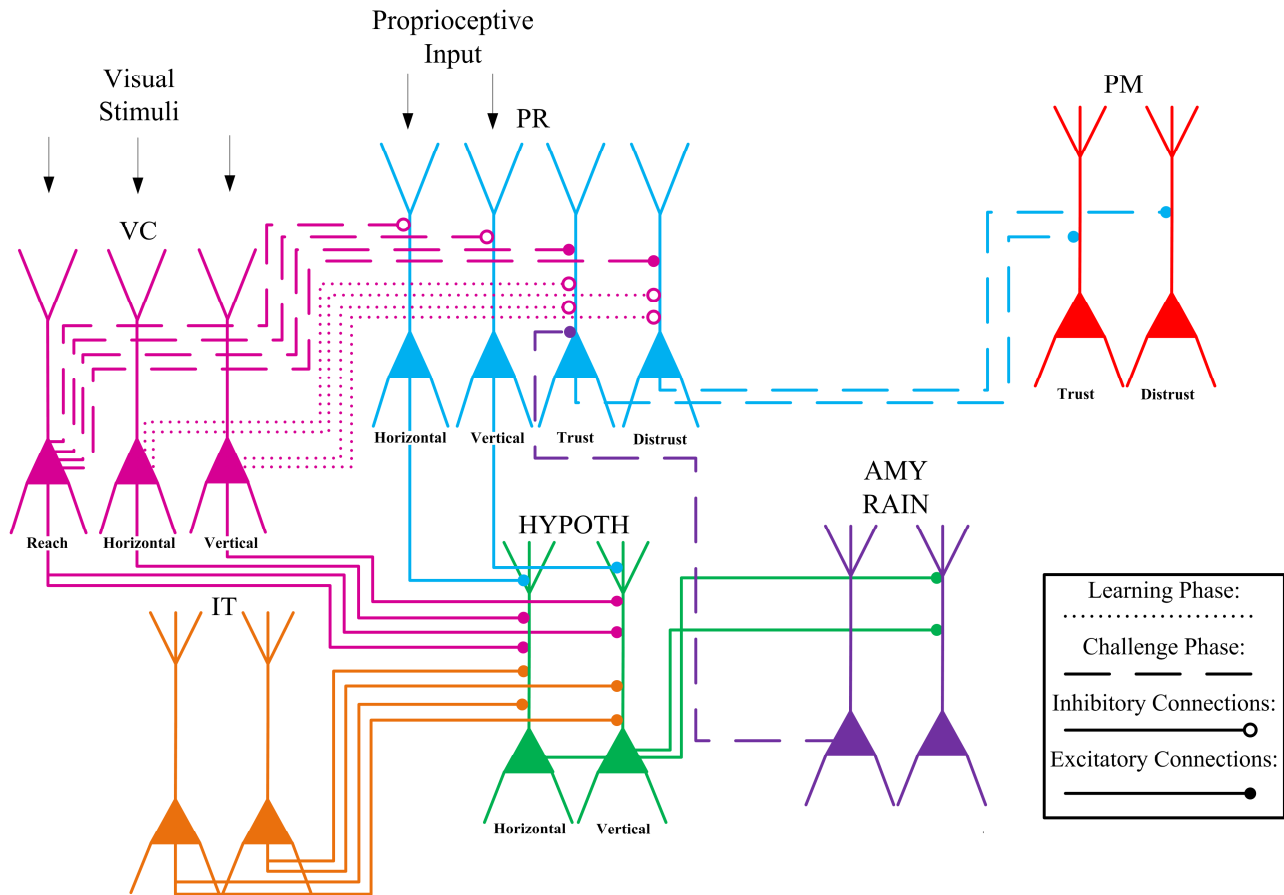


Fig. 3: Computational Neuromorphic Brain Architecture of the Instinctual Trust-the-Intent Scenario. During the learning phase, the dominant pathway depends on vertical or horizontal motions (dotted line) while during the challenge phase, it depends on the reaching action (dashed line). (VC: Visual Cortex; PR: Parietal Cortex; PM: Premotor; IT: Inferotemporal; HYPOTH: Hypothalamus; AMY: Amygdala).

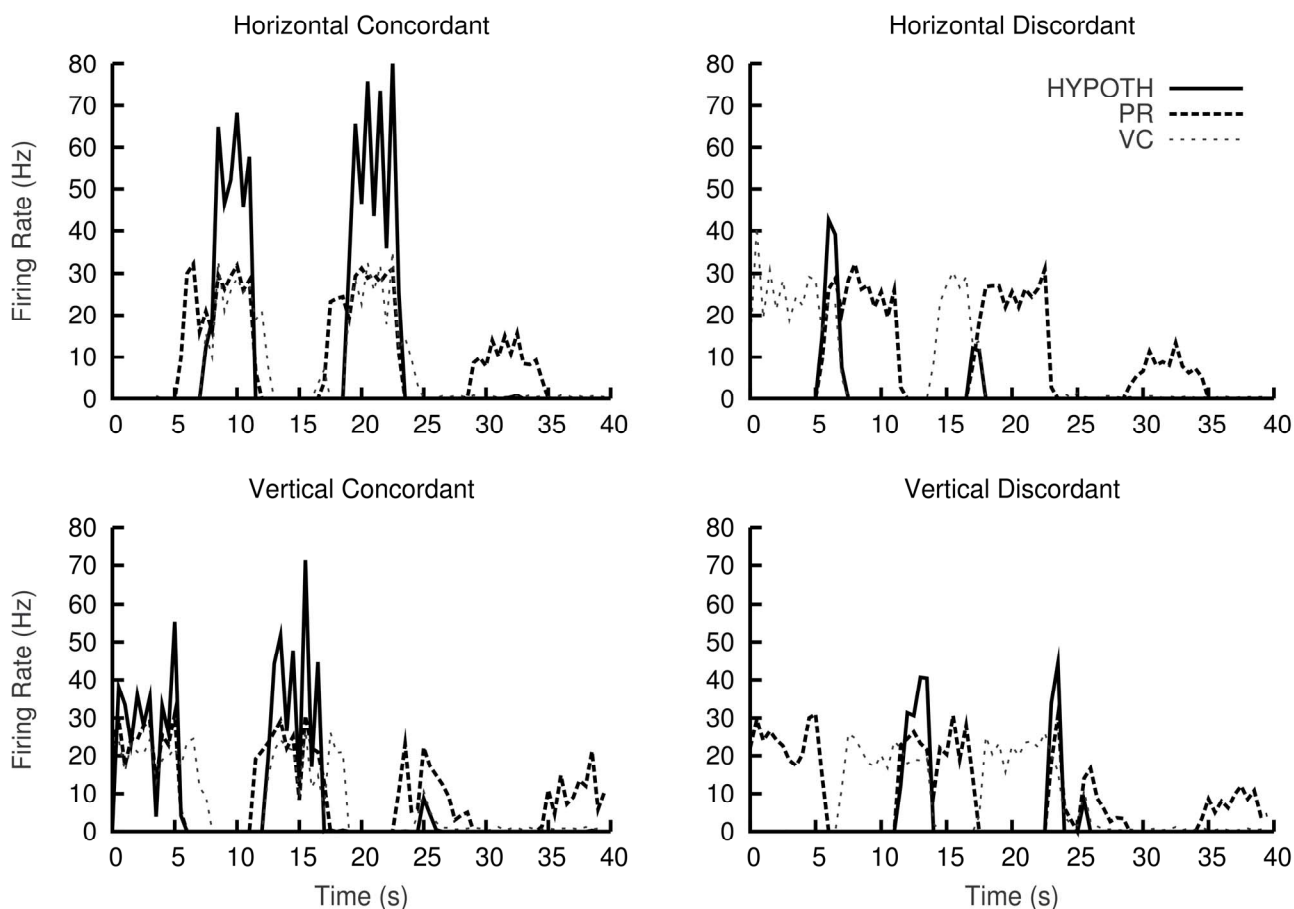


Fig. 4: Hypothalamic and Cortical Activities during both Concordant and Discordant Motions. Firing rates of three regions (VC: Visual Cortex; PR: Parietal Cortex; HYPOTH: Hypothalamus) are represented during horizontal concordant (top left), horizontal discordant (top right), vertical concordant (bottom left), and vertical discordant (bottom right) motions.

III. RESULTS

After the injection of a monotonic stimulus (40 seconds) into the inferotemporal cortex the activity in the visual and parietal cortices corresponded to the human and robot motions along with the hypothalamic firing as shown in Fig. 4. Significant firing rates (up to 80 Hz above baseline) occurred in the hypothalamus during concordant motions since the activities of the inferotemporal, visual, and parietal cortices overlap in the hypothalamus (Fig. 4 horizontal and vertical concordant). However, insufficient consistent firing occurred in the hypothalamus because of discordant activities in the visual and parietal cortices, even though there was the same stimulus from the inferotemporal cortex (Fig. 4 horizontal and vertical discordant).

Since the visual, parietal, and inferotemporal cortices connected to the independent dendrites of the hypothalamus, firing occurred only when all three dendrites integrated and fired together. Spiking in the independent dendrites of the hypothalamus occurred in the case of concordant actions as the neurorobot learned to trust the human. However, in the case of discordant motions dendritic firing within the hypothalamus decreased.

During reaching, a relatively significant firing rate (up to 30 Hz above baseline) occurred in only one of the parietal

decision-making cortical columns, which depended on the types of motion (concordant or discordant). Fig. 5 (left, concordant) shows higher firing rates in the parietal trust column when compared to the distrust column during concordant robot-human motions. In this figure, the firing started at 25 seconds since a reach for an object was performed at that time. In Fig. 5 (right, discordant), the parietal distrust column fired more when compared to the trust column during the discordant robot-human motion.

Additionally, the synaptic weight distributions of the vertical and horizontal columns for both concordant and discordant motions over a period of 40 seconds differed greatly. Whether the motion was vertical or horizontal, there was a significant increase in the synaptic weight due to STDP for concordant motions, which was twice higher compared to discordant motions. Also, in the case of concordant robot-human motions, after significant learning to trust a person has occurred then the firing in the hypothalamus was strong enough to inhibit the activity in the amygdala, which shut down the RAIN activity. However, in the case of discordant robot-human motions because there was insufficient or no firing in the hypothalamus the activity in amygdala remained active.

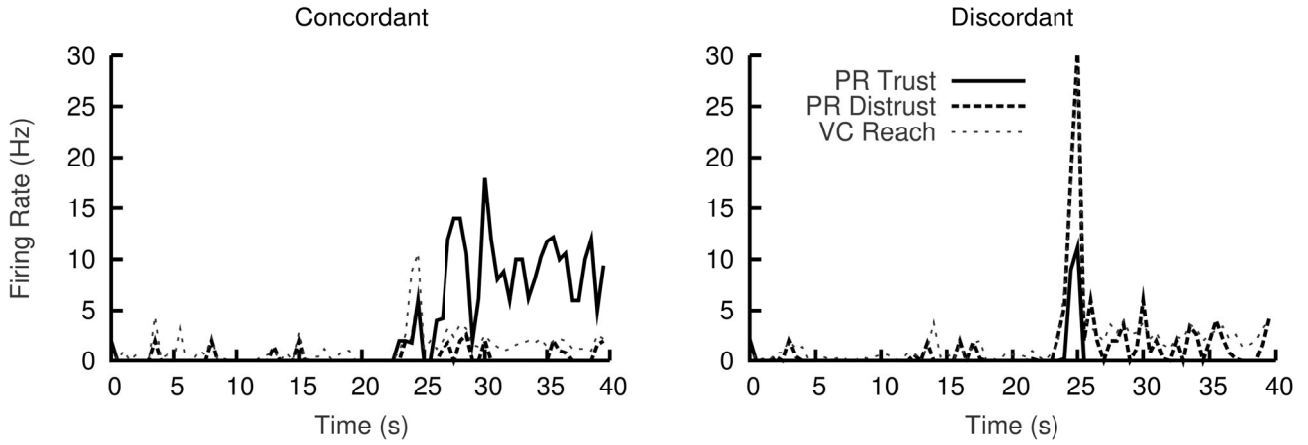


Fig. 5: Activity in Cortical Columns during Reaching. Firing rates of three regions (PR trust: Parietal Cortex trust column; PR distrust: Parietal Cortex distrust column; VC reach: Visual Cortex during reaching) are represented during reaching, and after concordant (left) or discordant (right) motions occurred.

IV. CONCLUSION

We modeled unique biological aspects of a mammalian brain related to the establishment of trust, such as the firing in the hypothalamus based on dendritic potentials, the role of oxytocin in trust and the introduction of a RAIN network in the amygdala. The objective of increasing cooperativity between a virtual neurorobot and a human was achieved, in which dendritic release of oxytocin into the hypothalamus [36-39] is strengthened by reinforcement learning [40] for concordant actions. This in turn inhibited the amygdala, which was responsible for cutting down cortical decision-making circuits. Thus, the trust levels of the virtual neurorobot went up; otherwise, there was no trust due to the lack of inhibition in the amygdala. The hypothalamic oxytocin cell model was developed as a realistic four-compartment triple apical dendrite model where each dendrite received stimulus from one of the three cortical columns: visual, parietal, and inferotemporal cortices. The three dendrites together fired the hypothalamus and thus the synapses connecting from the inferotemporal cortex to one of the dendrites of hypothalamus learned to trust a human. We introduced a self-sustaining RAIN network in the amygdala to maintain a background activity similar to that of humans, which turned off completely after sufficient learning has occurred.

Our findings replicated the experimental results of Paukner et al. (2009), who performed biological experiments on capuchin monkeys and concluded that these monkeys display affiliation towards humans who imitate them [5]. Similarly, in our model, the virtual humanoid neurorobot established trust with an interacting human partner who imitated it. Although in this model imitation was required in establishing trust, the paradigm could conceivably be extended to other experimental models of social learning, such as studies of vocal learning and mirror neurons [41].

The visual stimulus plays a dominant role in the VNR paradigm presented here and the results demonstrate that that role is sufficient in the decision making process. This visual dependence has been illustrated in other studies but is

not a requirement in establishing trust [42]. As more advanced architectures are constructed based on these results additional external stimulus can complement or replace the visual cues.

A limitation of this model is that the VNR loop fails to run in hard real-time. At this time this is due to insufficient processing power needed to handle RAIN networks and the forward and reverse conductance between soma and dendrites of the hypothalamus. We investigated this situation by shutting down the RAIN network in the amygdala and injecting a monotonic stimulus. This showed that without RAIN networks the VNR loop runs in perfect real-time on our current hardware. Future work will focus on enhancing the VNR loop such that it will run closer to real-time.

In addition, we plan to use the instinctual trust the intent model as a basis for building complex neuromorphic brain architectures related to memory, trustworthiness, and social phobia. These will be implemented on virtual and real robots in order to develop intelligent social agents using the VNR paradigm. Furthermore, gaining additional insights into the additional functions of oxytocin could provide insights and therapeutic benefits in other neurological disorders, such as autism [43, 44].

ACKNOWLEDGMENT

The authors would like to thank Dr. Monica Nicolescu for her sustained guidance and insightful recommendations.

The authors would also like to thank Nicholas Ceglia for his help with the figures.

DEDICATION

The authors dedicate this paper to Dr. Philip H. Goodman, a great mentor and friend who abruptly passed away recently.

REFERENCES

- [1] K. Dautenhahn, "Socially intelligent robots: dimensions of human-robot interaction," *Philos Trans R Soc Lond B Biol Sci*, vol. 362, pp. 679-704, 2007.
- [2] M. Scheutz, *et al.*, "First steps toward natural human-like HRI," *Autonomous Robotics*, vol. 22, pp. 411-423, 2007.
- [3] P. H. Goodman, *et al.*, "Framework and implications of virtual neurorobotics," *Frontiers in Neuroscience*, vol. 2, pp. 123-128, 2008.
- [4] S. Saavedra, *et al.*, "Cooperation under Indirect Reciprocity and Imitative Trust," *PLoS One*, vol. 5, p. Article No.: e13475, 2010.
- [5] A. Paukner, *et al.*, "Capuchin Monkeys Display Affiliation Toward Humans Who Imitate Them," *Science*, vol. 325, pp. 880-883, 2009.
- [6] K. A. Tahboub, "Compliant human-robot cooperation based on intention recognition," in *Intelligent Control. Proceedings of the 2005 IEEE International Symposium on, Mediterrean Conference on Control and Automation.*, Limassol, 2005, pp. 1417-1422.
- [7] R. Kelley, "Mind reading for social robots: stochastic models of intent recognition," Master's, University of Nevada, Reno, NV, 2009.
- [8] G. Domes, *et al.*, "Oxytocin improves "mind-reading" in humans," *Biological Psychiatry*, vol. 61, pp. 731-733, 2007.
- [9] U. Rimmele, *et al.*, "Oxytocin Makes a Face in Memory Familiar," *Journal of Neuroscience*, vol. 29, pp. 38-42, 2009.
- [10] M. Kosfeld, *et al.*, "Oxytocin increases trust in humans," *Nature*, vol. 435, pp. 673-676, 2005.
- [11] P. J. Zak, *et al.*, "Oxytocin is associated with human trustworthiness," *Hormones and Behavior*, vol. 48, pp. 522-527, 2005.
- [12] T. Baumgartner, *et al.*, "Oxytocin shapes the neural circuitry of trust and trust adaptation in humans," *Neuron*, vol. 58, pp. 639-650, 2008.
- [13] P. Kirsch, *et al.*, "Oxytocin modulates neural circuitry for social cognition and fear in humans," *Journal of Neuroscience*, vol. 25, pp. 11489-11493, 2005.
- [14] P. Petrovic, *et al.*, "Oxytocin attenuates affective evaluations of conditioned faces and amygdala activity," *Journal of Neuroscience*, vol. 28, pp. 6607-6615, 2008.
- [15] D. Huber, *et al.*, "Vasopressin and oxytocin excite distinct neuronal populations in the central amygdala," *Science*, vol. 308, pp. 245-248, 2005.
- [16] M. Heinrichs, *et al.*, "Oxytocin, vasopressin, and human social behavior," *Frontiers in Neuroendocrinology*, vol. 30, pp. 548-557, 2009.
- [17] K. Uvnas-Moberg, "Antistress pattern induced by oxytocin," *News in Physiological Sciences*, vol. 13, pp. 22-26, 1998.
- [18] K. Uvnas-Moberg, "Oxytocin may mediate the benefits of positive social interaction and emotions," *Psychoneuroendocrinology*, vol. 23, pp. 819-835, 1998.
- [19] T. L. Bale, *et al.*, "CNS region-specific oxytocin receptor expression: Importance in regulation of anxiety and sex behavior," *Journal of Neuroscience*, vol. 21, pp. 2546-2552, 2001.
- [20] K. Ebner, *et al.*, "Release of oxytocin in the rat central amygdala modulates stress-coping behavior and the release of excitatory amino acids," *Neuropsychopharmacology*, vol. 30, pp. 223-230, 2005.
- [21] K. J. Parker, *et al.*, "Intranasal oxytocin administration attenuates the ACTH stress response in monkeys," *Psychoneuroendocrinology*, vol. 30, pp. 924-929, 2005.
- [22] H. E. Ross and L. J. Young, "Oxytocin and the neural mechanisms regulating social cognition and affiliative behavior," *Frontiers in Neuroendocrinology*, vol. 30, pp. 534-547, 2009.
- [23] G. Domes, *et al.*, "Oxytocin attenuates amygdala responses to emotional faces regardless of valence," *Biological Psychiatry*, vol. 62, pp. 1187-1190, 2007.
- [24] P. J. Whalen, *et al.*, "Human amygdala responsivity to masked fearful eye whites," *Science*, vol. 306, pp. 2061-2061, 2004.
- [25] A. Ohman, "The role of the amygdala in human fear: Automatic detection of threat," *Psychoneuroendocrinology*, vol. 30, pp. 953-958, 2005.
- [26] E. Choleris, *et al.*, "Microparticle-based delivery of oxytocin receptor antisense DNA in the medial amygdala blocks social recognition in female mice," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 104, pp. 4670-4675, 2007.
- [27] P. H. Goodman, *et al.*, "Virtual neurorobotics (VNR) to accelerate development of plausible neuromorphic brain architectures," *Frontiers in Neurobotics*, vol. 1, pp. 1-7, 2007.
- [28] R. Brette, *et al.*, "Simulation of networks of spiking neurons: A review of tools and strategies," *Journal of Computational Neuroscience*, vol. 23, pp. 349-398, 2007.
- [29] J. P. Jones and L. A. Palmer, "AN EVALUATION OF THE TWO-DIMENSIONAL GABOR FILTER MODEL OF SIMPLE RECEPTIVE-FIELDS IN CAT STRIATE CORTEX," *Journal of Neurophysiology*, vol. 58, pp. 1233-1258, 1987.
- [30] R. Mehrotra, *et al.*, "GABOR FILTER-BASED EDGE-DETECTION," *Pattern Recognition*, vol. 25, pp. 1479-1494, Dec 1992.
- [31] L. C. Jayet Bray, *et al.*, "A circuit-level model of hippocampal place field dynamics modulated by entorhinal grid and suppression-generating cells," *Frontiers in Neural Circuits*, vol. 4, pp. 1-12, 2010.
- [32] T. P. Vogels and L. F. Abbott, "Signal propagation and logic gating in networks of integrate-and-fire neurons," *Journal of Neuroscience*, vol. 25, pp. 10786-10795, 2005.
- [33] N. Brunel, "Dynamics of sparsely connected networks of excitatory and inhibitory spiking neurons," *Journal of Computational Neuroscience*, vol. 8, pp. 183-208, 2000.
- [34] F. Mormann, *et al.*, "Latency and selectivity of single neurons indicate hierarchical processing in the human medial temporal lobe," *Journal of Neuroscience*, vol. 28, pp. 8865-8872, 2008.
- [35] Q. Peng, "Brainstem: A neocortical simulator interface for robotic studies," Master's, University of Nevada, Reno, NV, 2006.
- [36] A. O. Komendantov, *et al.*, "Somato-dendritic mechanisms underlying the electrophysiological properties of hypothalamic magnocellular neuroendocrine cells: A multicompartmental model study," *Journal of Computational Neuroscience*, vol. 23, pp. 143-168, 2007.
- [37] I. D. Neumann, "Stimuli and consequences of dendritic release of oxytocin within the brain," *Biochemical Society Transactions*, vol. 35, pp. 1252-1257, 2007.
- [38] F. Bergquist and M. Ludwig, "Dendritic transmitter release: A comparison of two model systems," *Journal of Neuroendocrinology*, vol. 20, pp. 677-686, 2008.
- [39] N. Sabatier, *et al.*, "Central release of oxytocin and the ventromedial hypothalamus," *Biochemical Society Transactions*, vol. 35, pp. 1247-1251, 2007.
- [40] R. Hurlemann, *et al.*, "Oxytocin Enhances Amygdala-Dependent, Socially Reinforced Learning and Emotional Empathy in Humans," *Journal of Neuroscience*, vol. 30, pp. 4999-5007, 2010.
- [41] W. T. Fitch, *et al.*, "Social Cognition and the Evolution of Language: Constructing Cognitive Phylogenies," *Neuron*, vol. 65, pp. 795-814, 2010.
- [42] A. Tosoni, *et al.*, "Sensory-motor mechanisms in human parietal cortex underlie arbitrary visual decisions," *Nature Neuroscience*, vol. 11, pp. 1446-1453, 2008.
- [43] E. Hollander, *et al.*, "Oxytocin infusion reduces repetitive behaviors in adults with autistic and Asperger's disorders," *Neuropsychopharmacology*, vol. 28, pp. 193-198, 2003.
- [44] E. Andari, *et al.*, "Promoting social behavior with oxytocin in high-functioning autism spectrum disorders," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 107, pp. 4389-4394, 2010.