Visual and Auditory
Neuroscience Lab

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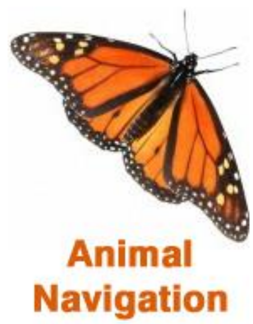
Welcome to the Visual and Auditory Neuroscience Labs

Directed by Dr. Barrie Frost

We are located in the Department of Psychology at Queen's University in Kingston, Ontario (Canada).
The primary research focus in our lab is on brain mechanisms for processing visual and auditory information, but many behavioural studies related to various aspects of sensory perception in animals and humans are also undertaken.



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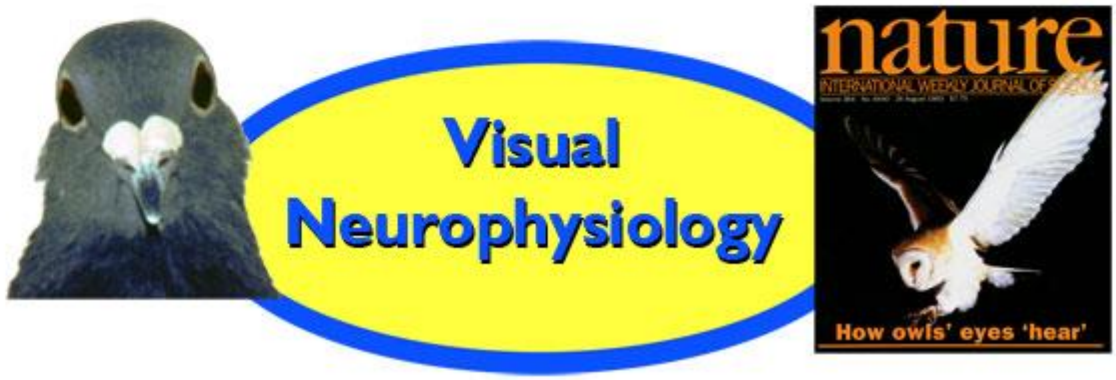
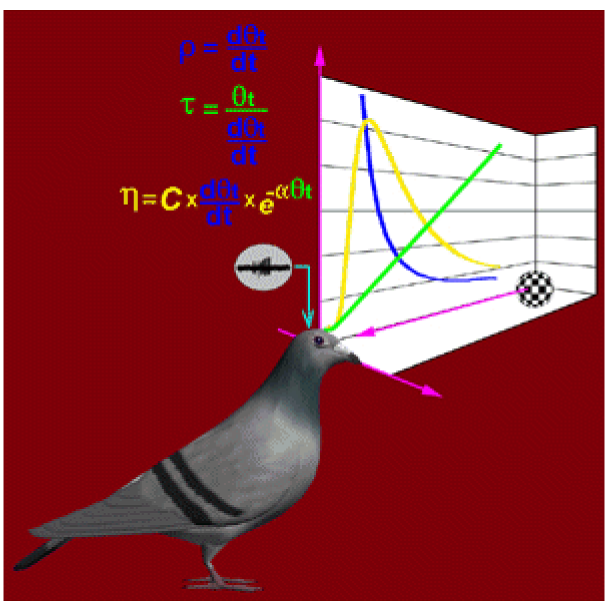


A main focus of our lab is to investigate the functions of the visual system by using various animal models. Our research includes analyzing the responses of cells in the pigeon optic tectum, Nucleus Rotundus and various other visual nuclei. Using Silicon Graphics workstations (Octane) we are able to create many visual stimuli which we can move in 2D or 3D trajectories. These stimuli are presented on a tangent screen and a Spike2 program running on a Pentium4 Computer controls the presentation of stimuli. The collection of data (neuronal impulses) with millisecond resolution are recorded on the PC using Spike2. Using these procedures we have discovered neurons that are specialized for processing object motion, colour, motion of objects in 3D space, time to collision, etc. Other visual pathways have been studied which appear to be processing self-induced optic flow.

Time to Collision



We have found neurons in the pigeon Nucleus Rotundus which are highly selective for objects which are going to collide with the animal and the cells appear to calculate the time to collision.

Wang, Y.C. and **Frost, B.J.** Some neurons in the nucleus rotundus of pigeon compute time to collision. *Society for Neuroscience Abstract*, 1991, 17, 1380.

Wang, Y. and **Frost, B.J.** "Time to collision" is signalled by neurons in the nucleus rotundus of pigeons. *Nature*, 1992, 356, 236-238. (Written up in Current Biology, 1992, 2, 371-372).

Wang, Y., Jiang, S. and **Frost, B.J.** Visual processing in pigeon nucleus rotundus: luminance, colour, motion and looming subdivisions. *Visual Neuroscience*, 1993, 10, 21-31.

Sun, H.-J. and **Frost, B.J.** Responses of time-to-collision neurons in the nucleus rotundus of pigeons to accelerating and decelerating stimuli. Society for Neuroscience Abstract, 1997, 23, 453.

Frost, B. J. and Sun, H.-J. Responses of looming detectors in the nucleus rotundus of pigeon. Association for Research in Vision and Ophthalmology Abstract, 1997.

Sun, H.-J. and Frost, B.J. Computation of different optical velocities of looming objects. Nature Neuroscience, 1998, 1(4), 296-303. [See Selected Abstracts section]

Objects and Holes

We are also studying the motion cues for determining figure ground relationships of objects. We have found cells that respond specifically to textured objects moving "in front" of textured backgrounds, but do not respond to "holes" or apertures in textured fields. These cells seem to be responding to moving "occlusion" edges and not disocclusion edges.

Frost, B.J., Wang, Y-C. and Jiang, S-Y. Leading edge occlusion specificity in tectal and n. isthmi cells in the pigeon. *ARVO Abstracts*, 30, 300, 1989.

Wang, Y.C. and **Frost, B.J.** Functional organization in the nucleus rotundus of pigeon. *Society for Neuroscience Abstract*, 1990, 16, 1314.

Frost, B.J. Subcortical Analysis of Visual Motion: Relative motion, figure-ground discrimination and self-induced optic flow. In F.A. Miles, and J. Wallman (Eds.). *Visual Motion and its role in the Stabilisation of Gaze*. Elsevier, Amsterdam, 1993, 159-175.

Frost, B.J. and Sun, H.J. Visual motion processing for figure/ground segregation, collision avoidance, and optic flow analysis in the pigeon. Chapter 5. In: M.V. Srinivasan and K. Venkatesh (eds.) *From Living Eyes to Seeing Machines*, Oxford University Press, London, 1997, 80-103.

Motion Integration over long distances

Another area of interest in our lab is on the differences between long range excitatory and inhibitory interactions between neurons which code motion. We are currently involved in examining these issues in the object motion pathway as well as the self motion pathway in the pigeon. These experiments relate to our human psychophysics experiments on motion capture and vection (see below) and also to our work on Virtual Reality.

Sun, H.-J. and **Frost, B.J.** Motion processing in pigeon tectum: Equiluminant chromatic mechanisms. *Experimental Brain Research*, 1997, 116, 434-444.

Human Vection: Ambiguous cues to vection

We study the perception of self motion in humans using a Vection booth. An Amiga 3000 computer is used to generate animated whole field motion patterns which are projected on two adjacent corner wall-screens of a darkened cubical booth. With the presentation of appropriate visual stimuli the subjects achieve the overwhelming sensation that they are in an elevator moving up or down. We have investigated the relationship between the depth of the stimuli presented and the self motion sensations. We have also examined the effects of ambiguous vection stimuli on the phenomenon. We presented visual patterns with an equal amount of up and down motion with either no spatial separation (transparent) or within a checkerboard pattern with alternating up and down motion squares. Subjects still experienced vection despite the absence of a net motion signal. Furthermore the subjects experienced a profound kinetic depth effect which appeared to determine the direction of vection. The kinetic depth effect was bistable with the set of up dots becoming the background for a period and then the set of down dots becoming the background. With each flip of depth there was a corresponding flip in the direction of vection.

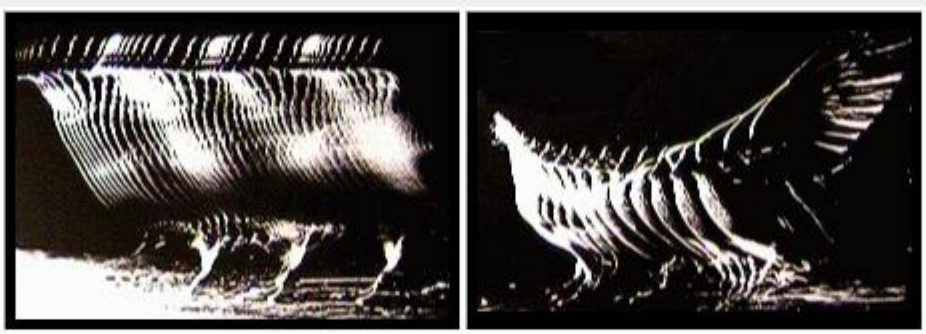
Telford, L., Spratley, J. and **Frost, B.J.** The role of kinetic depth cues in the production of linear vection in the central visual field. *Perception*, 1992, 21, 337-349.

Telford, L. and **Frost, B.J.** Factors affecting the onset and magnitude of linear vection. *Perception and Psychophysics*, 1993, 53, 682-692.

Marlin, S.G., Feldman, R. and **Frost, B.J.** Ambiguous foreground/background motion cues and vection. *Association for Research in Vision and Ophthalmology Abstracts*, 1994, 35:1276.

Animal Vection

We are studying the behavioural responses of animals (Pigeons and Locusts) to various speeds of whole field motion patterns. Translocational visual flow fields can produce head bobbing in pigeons and flight in tethered locusts.



Pigeon Head Bobbing | Pigeon Landing

Pigeon Bobbing Pigeon Landing

Troje, N. and **Frost, B.J.** Head-bobbing in pigeons: How stable is the hold phase? *Journal of Experimental Biology*, 2000, 203:935-940. (Written up in New Scientist, 165(2227):23).

Troje, N.F. and **Frost, B.J.** The physiological fine structure of motion sensitive neurons in the pigeon's tectum opticum. *Society for Neuroscience Abstract*, 1998.

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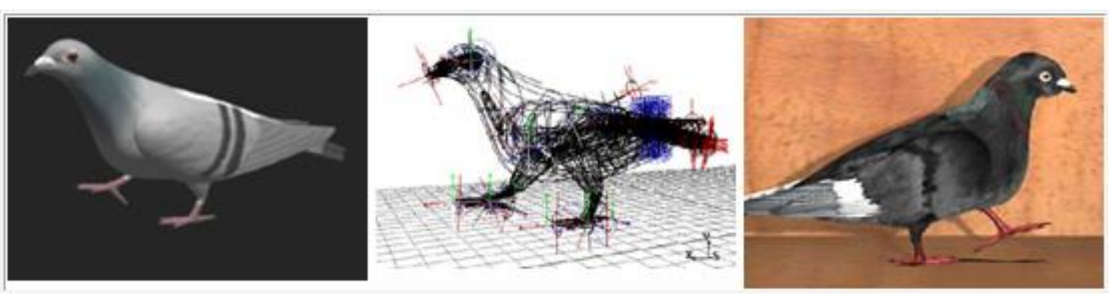
In 1998 we initiated a program to study the neuroethology of conspecific recognition in pigeons, having shown convincingly they produce robust courtship responses to video images.

In collaboration with Dr. Nikolaus Troje we have constructed a virtual pigeon, using professional animation programs (Alias|Wavefront Maya, Kaydara MoCap), that will exhibit most of the behaviour of real pigeons, where moving parts are under computer control. Click here to view a video of a Virtual "Female" Pigeon, which is a receptive female modeled after a live female.



Various versions and wire framing of the Virtual Pigeon

We will use miniature FM telemetry units to transmit single unit data from pigeons as they observe and respond to these well controlled video and virtual animals in order to find the brain areas involved in courtship behaviour.

Frost, B.J., Troje, N.F. and David, S. Pigeon courtship behaviour in response to live birds and video presentations. *5th International Congress of Neuroethology*, 1998.

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Troje, N.F., **Frost, B.J.** and David, S. An ethogram of the pigeon's bowing display. *5th International Congress of Neuroethology*, 1998.

Troje, N.F. and **Frost, B.J.** The physiological fine structure of motion sensitive neurons in the pigeon's tectum opticum. *Society for Neuroscience Abstract*, 1998.

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Monarch Butterflies

Monarch butterflies (Danaus plexippus) from the eastern North American population make remarkably long migratory journeys in the autumn, some extending more than 3,500 km from Eastern USA and Canada to over-wintering grounds in the neovolcanic belt in Central Mexico. See their migration map. Follow the Monarch's spring and fall migration via Journey North.

This research is conducted in collaboration with Dr. Henrik Mouritsen, University of Oldenburg, Germany.

Figure 1

Flight in tethered insects is typically induced by directing a flow of air horizontally toward their heads. We have developed a novel flight simulator apparatus that directs the flow of air vertically from beneath the butterflies (Fig. 1). Click here to view a movie of their simulator flight. RealPlayer video, size 1593KB.

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A very low friction bearing allows the butterflies to steer their intended flight directions to any point of the compass, while their headings are continuously recorded by an optical encoder and computer. This allows us to reconstruct long segments of their virtual migratory journey (Fig 2.).

But what does the Monarch Butterfly use to navigate to a location they have never been to? Do they use the sun itself, the sky's polarization pattern or some combination, or do they use the earth's magnetic field? See How do Monarch Butterflies (Danaus plexippus) Navigate to Mexico?

We have shown that monarchs use a time-compensated sun compass but not a magnetic compass, during migratory flight (Fig. 2). Monarchs flown under a natural sunny sky oriented southwest (Fig. 2A), those clockshifted ±6 hours, shifted their orientation 90° (Fig. 2B,C), while those tested under simulated overcast conditions were not significantly oriented suggesting that they were not using the natural magnetic field for orientation (Fig. 2D). See Mouritsen & Frost (2002).

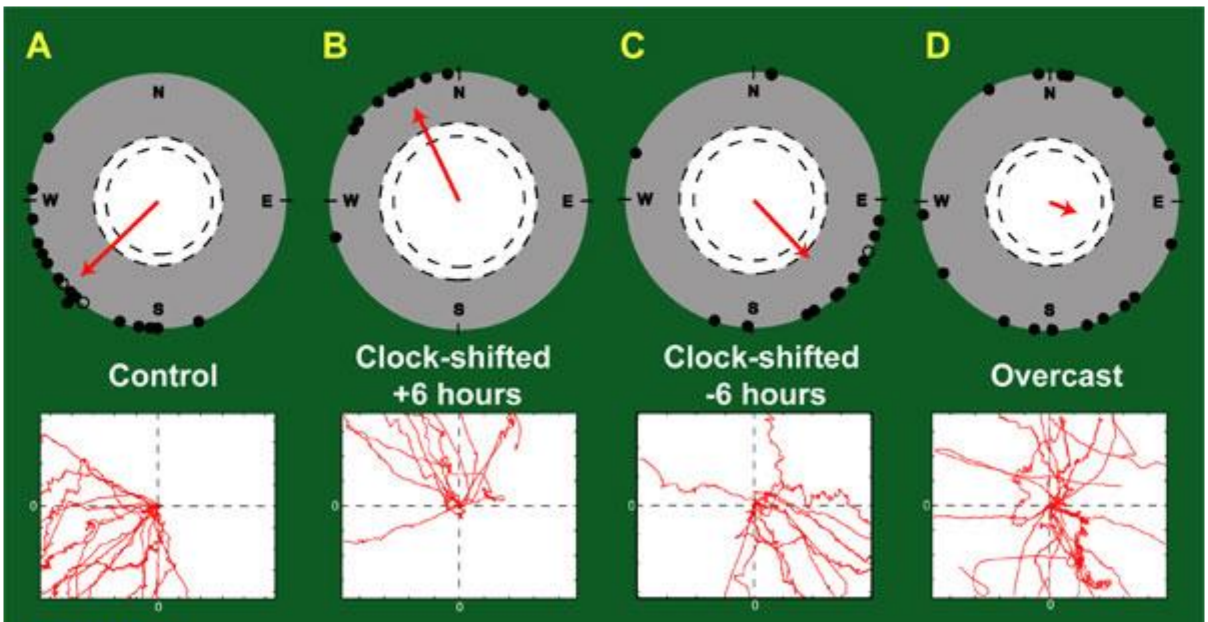

Figure 2

Figure 3: Overpainted dorsal rim area of the monarch eye

To test if migratory Monarch Butterflies use polarized light patterns as part of their time-compensated sun compass, butterflies were exposed to patches of naturally polarized blue sky, artificial polarizers or a sunny sky. In addition, we tested butterflies with and without the polarized light detectors of their compound eye being occluded (Fig 3).

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Figure 4 shows the orientation of monarchs tested under various flight conditions. (A & B) 44° UVA-containing stimulus; (D & E) 85° UVA-containing stimulus without sunshades; (G & H) 85° UVA-containing stimulus with sun shades. None of the polarized light stimuli led to time-compensated compass orientation based on the orientation of the polarizer.

When given a direct view of the sun, migratory monarchs with their polarized light detectors painted out were still able to use their time-compensated compass (Fig. 4C, dorsal-rim not occluded; Fig. 4F, dorsal rim area occluded).

We conclude that in migratory monarch butterflies, polarized light cues are not necessary for a time-compensated celestial compass to work and that the azimuthal position of the sun disc and/or the associated light-intensity and spectral gradients seem to be the migrants' major compass cue. See Stalleicken et al., 2005.

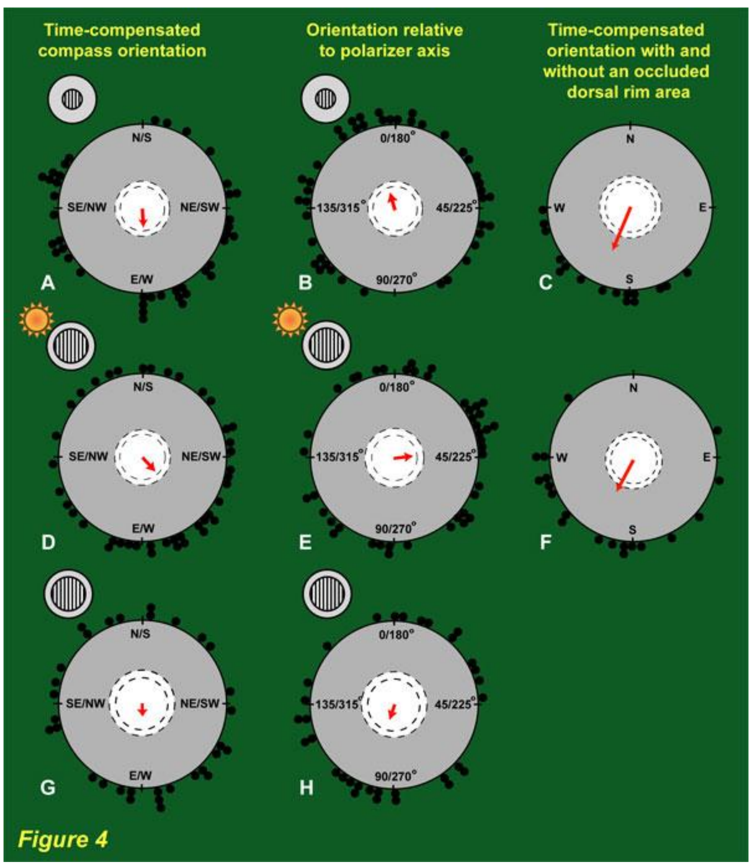

Figure 4

Mouritsen, H. and **Frost, B.** 2002. Virtual migration in tethered flying monarch butterflies reveals thier orientation mechanisms, Proceedings of the National Academy of Science 99(15):10162-10166. [View Online Publication]

Stalleicken, J., Mukhida, M., Labhart, T., Wehner, R., **Frost,** B. & Mouritsen, H. 2005. Do monarch butterflies use polarized skylight for migratory orientation? Journal of Experimental Biology 208:2399-2408. [View Online Publication]

Seabirds

How do seabirds find their way? We know from previous work that migratory songbirds use at least two compasses, a magnetic compass and a celestial compass. These are known to work independently of each other. In comparison, no data are available from seabirds. The emergence of satellite transmitters have made studies of the navigational strategies of seabirds possible, since we can now follow individual birds.

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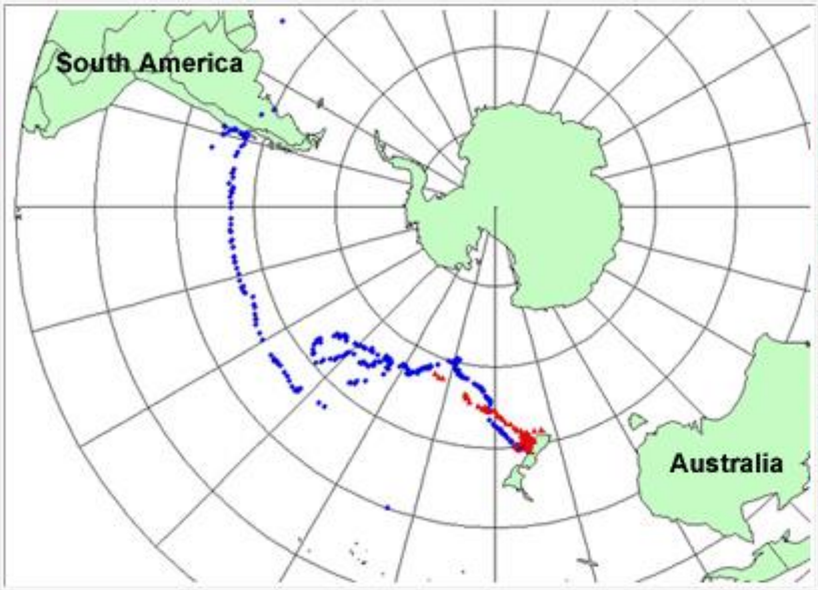
We have conducted navigation studies on the Waved Albatross in the Galápagos Marine Reserve in collaboration with Dr. Dave Anderson of Wake Forest University and on Sooty Shearwaters in New Zealand in collaboration with Dr. Henrik Moller of the University of Otago on the Keep the Titi Forever project.



Map showing satellite tracking of Sooty Shearwaters in New Zealand during 2000. Note the long trip of the Shearwater that flew to Chile (blue track). The bird appeared to be turning back when the transmitter battery went dead. During the 2001 breeding season this bird returned to its New Zealand burrow.

Anderson, D.J., Huyvaert, K.P., Wood, D.R., Gillikin, C.L., **Frost, B.J.** and Mouritsen, H. At-sea distribution of Waved Albatrosses and the Galápagos Marine Reserve. Biological Conservation, 2003, 110:367-373.

Mouritsen, H., Huyvaert, K.P., **Frost, B.J.** and Anderson, D.J. Waved albatrosses can navigate without a functional magnetic compass. Journal of Experimental Biology, 2003, 206, 4155-4166.

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The Purpose of the Virtual Reality Group

Our primary purpose in venturing into the field of virtual reality is to bring our knowledge of multisensory perceptual mechanisms to the technical advancement of Virtual and Artificial Perceptual Environment Research (VAPER). We do this by exploring the perceptual consequences of various types of stimuli and body motion constraints. We are also involved in research into basic perceptual mechanisms using human and animal models behaviour and physiology). Much of our work focuses on the distinctions between self motion and object motion and the segregation of objects using motion cues.

Overview of our present system

We have built several VR platforms. A virtual world is generated using custom made programs in OpenGL on Silicon Graphics Workstations and is presented on a Virtual i/O light-weight head-mounted LCD display. Head tracking is accomplished using an Ascension Flock of Birds 6DOF head tracker mounted on the helmet strap. Our Cyber bike is a standard mountain bike that has been modified to allow real world motion of the bike wheel (using optical sensors) and the steering (using standard pots) to determine the speed and direction of movement in the virtual world.

The SGI takes the position information from the bike and uses this to compute the 3D arrangement of the objects in the virtual world. This is only possible due the the ability of the SGI to accept this data at high speeds and use the data to compute the 3D environment in almost real time.

In a large VR space subjects ride a stationary bicycle or walk on a treadmill to explore the full spatial extent of the space. The viewpoint is dynamic and is determined by the steering angle and translational velocity of either the modified stationary mountain bike or treadmill which is serially linked to the SGI workstation. Both of these means of transportation require very natural motor output on the part of the user and can be readily modified to simulate different large spaces ranging from city scapes (for architectural and design purposes) to large plants (to simulate safety and emergency procedures).

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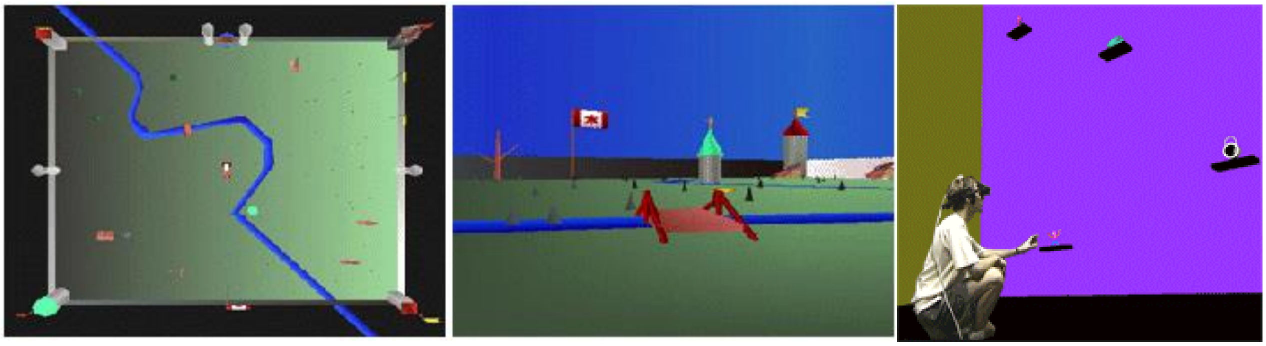

Medium and small space VRs provide small virtual worlds for critical experiments in animal and human sensory physiological experiments where natural interactions by way of head movements changes dynamic displays while activity in animal brains is being monitored.

- The various perceptual cues to depth and motion which enhance the perception of reality in VR.
- The role of interactive control in VR.
- Formation of spatial memory maps.
- 3D auditory VR space perception.

We have found that VRs do indeed allow human subjects to build very precise cognitive maps of the virtual spaces they explore, and that the natural interactions with a VR our systems provide lead to superior spatial knowledge of the spaces we simulate. This then really validates what many people had expected from this technology.

Tong, F.H., Marlin, S.G., and **Frost, B.J.** Cognitive Map Formation in a 3D Visual Virtual World. *IRIS/PRECARN Workshop*, 1995.
Marlin, S.G., Tong, F., David, S. and **Frost., B.** Testing Cognitive Maps of Immersive 3D Virtual Reality Environments. *Proceedings of the 4th conference of the Australasian Cognitive Science Society*, 1997.

Marlin, S.M. and **Frost, B.J.** Incidental learning and memory of object location resulting from naturalistic exploration in a Virtual Reality room: one wall (2D object location), two or four wall (true 3D) object placement. *IRIS/Precarn Conference*, 1997.

The best human interest story is that when we designed a simple VR environment to test what information humans use to brake successfully (i.e. while riding their bike in a virtual world and stopping in front of a barrier) it was precisely the same information, Tau, that is used universally over the animal kingdom. For example, flies use this same tau margin to effect effortless and safe landings, and gannets use it to fold their wings during 100 metre dives into the sea.

Sun, H.J. and **Frost, B**.J. Visual control of target-directed locomotion in a virtual environment. IRIS/Precarn Conference, 1998.

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Using pigeons we study how simple or complex sounds, ranging from infrasound to higher frequencies are processed in the brain. We are also interested in the sound localization (and auditory "figure/ground" segregation) abilities of birds and mammals, and use owls and rats for these experiments. Our experiments are conducted in an anechoic chamber equiped with a moveable speaker array. A customized auditory program running on our IBM computer allows us to produce white noise, various tones, from infrasound to higher frequencies, and complex sounds including species specific vocalizations. The auditory program also analyzes the data obtained from the various auditory neurons.

Frost, B.J. and Li, L. EMG response of pinnae muscles to azimuthal variations of free-field sounds in decerebrate rats. *Society for Neuroscience Abstracts*, 1995.

Wild, J.M., Karten, H.J. and **Frost, B.J.** Connections of the auditory forebrain of the pigeon (Columba livia). *Journal of Comparative Neurology*, 1993, 337, 32-62.

Frost, B.J., Baldwin, J. and Csizy, M. Auditory localization in the Saw-Whet Owl, Aegolius acadicus. *Canadian Journal of Zoology*, 1989, 67, 1955-1959.

Wise, L.Z., **Frost, B.J.**, Shaver, S.W. The representation of sound frequency and space in the mid brain of the Saw-Whet Owl. *Society for Neuroscience Abstracts*, 1988, 14, 1095.