Research in Progress
(and/or Unpublished)


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Allometry of Trees

*Forest Allometry (started ca. 1967)* I have a long-standing interest in the geometrical structure of forests and its implications for growth, regeneration, and diversity of trees, as well as for foraging behavior and microhabitat choice by birds. Accordingly I try to develop simple yet sufficient ways of measuring this geometrical structure. The project encompasses everything from deciding which
parameters are most important for trees and birds, to testing hierarchical caricatures of prohibitively tedious measurements (like a true measure of leaf area per unit of ground area), to inventing simpler machinery and faster techniques to do the measurements. This project is always “bubbling on the back burner,” ever since R. H. Mac Arthur and H. S. Horn, 1969, Foliage profiles by vertical measurements, *Ecology* 50: 802-804.

**Hydraulic Architecture (started 2004)** I am exploring the tapering of xylem vessels (= water “pipes”) in trees, in collaboration with Joshua Weitz and Kiona Ogle (former post-doctoral fellows in the Levin/Pacala lab). There is a large body of theory about the shapes of trees, their competition for water, and consequences for community structure and function, ... all based on indirect inferences about variation in vessel size in different parts of a tree, ... but ours are among the few direct measurements, and to our knowledge, the only ones that expressly test the theories. My part of the project concentrates on the choice and dissection of trees and the preparation and imaging of cross-sections, using novel staining techniques. Joshua has developed and validated automated measurements of thousands of vessels per image. And Kiona has designed the statistical analyses. Exhaustive analysis of several thousand measurements on a single white ash tree (*Fraxinus americana*) show that tapering is concentrated in peripheral twigs and small branches, with a stationary developmental allometry that is in partial quantitative agreement with a theory that constrains xylem vessels to make resistance to water flow be independent of path length (J. Weitz, K. Ogle, and H. S. Horn, 2006, Ontogenetically stable hydraulic design in woody plants, *Functional Ecology* 20: 191-199). Another project looks at xylem networks with cells connected via low longitudinal resistances and higher lateral resistances. The networks can be analyzed by successive applications of the “delta-wye transformation” from electrical engineering, ... and responses to tissue damage can be simulated. The most recent project looks at the distinctive “neighborhood” of photosynthetic cells at the end of the terminal vessels in leaves. My discovery (probably not original to me) is that this photosynthetic neighborhood is the same physical size in most local trees, shrubs, and vines, ... with most of the exceptions being larger neighborhoods in species of recent Tropical origin. Conversely, the density of stomata on the leaf surface varies dramatically among species. These observations pose several questions about adaptive physiology, which, if answered, will allow eco-physiological interpretation of simple field measurements.
Allometric Reconstruction of Competition (started 1995)

With the help of several undergraduates, Laura Lopez Hoffman (Princeton BA ’96, Stanford PhD ’03) and I did a series of explorations of the allometry of tree growth, and its consequences up to the level of the local landscape. This is one of several on-going projects at Princeton’s Stony Ford Field Center for Ecological Studies. We started by dissecting a tree, cutting geometrically mapped cross-sections from throughout its trunk and branches. The number of annual rings in each section gives the age of branches distal to that section. Subtracting this number from the age of the tree gives the age at which an extant branch first reached the location of that cross-section. So we can reconstruct the history of growth of the tree, of its nearest neighbors, and of its whole neighborhood. We have used this technique to explore the competition between red cedar (Juniperus virginiana) and white ash (Fraxinus americana) as forests develop in the first 50 years after fields have been abandoned from farming. The red cedar dominates for the first two decades, while the white ash grows very slowly. The white ash rises to co-dominance over the next twenty years, and then dominates and suppresses the red cedar for the last decade. The differential patterns of growth of two adjacent trees are reflected in the changes in dominance in their neighborhood, and in the compositions of old-field woodlands of different ages throughout much of central New Jersey. We plan to refine our measurement of growth to represent the volume of wood added annually, and its allocation to height versus width. We shall also see whether similar analyses can be done with surficial roots. If this allocation is subject to simple allometric rules, then we shall explore their consequences for patterns of carbon storage by growing forests. Students involved included: Gregg Furie BA ’97, Luis Solorzano PhD ’99, and students in my Forest Ecology course (EEB 317). Laura and I never seem able to get together to decide whose court the ball is in on publication, other than to agree that the one who sends it off gets senior authorship. Until then, a rudimentary seminar is available as: Scaling Succession: from Interactions between Adjacent Trees to Landscape Dynamics across Woodlots (Overhead transparencies, if I can find them).
Conservation of Cross-sectional Area (started 1995) In collaboration with many undergraduate students, I have tested an assertion by Leonardo da Vinci that, when a tree branches, the sum of cross sections beyond the node equals the cross section before the node. He derived this principle by assuming a conservation rule for water flow through a bundle of tiny, identical pipes. Were his mechanism true, his assertion should fail for species that concentrate their transport of water into the most recently formed, large vessels (“ring-porous” species).

Leonardo’s rule of cross-sectional conservation holds for many species of trees, regardless of differences in above-ground hydraulic architecture, ... and his rule often fails for roots, which have consistent hydraulic architecture. Apparently the cross-sectional conservation has more to do with elastic physical support than with hydraulics. Nevertheless, the fact of conservation means that the above-ground volume of wood in a tree can be estimated accurately from a few simple measurements. We have done this, and calculated the weight of above-ground carbon stored per unit of land area for a number of New Jersey trees. It turns out to be 2–20 times as much as the total amount of carbon in the atmosphere above isolated trees (and it reaches an asymptote of 3–8X in local forests). This result suggests that local trees are of greater regional significance in the global carbon budget than previously thought. Students involved in this project included: Rizwan Arastu BA ’97, Katherine McArthur BA ’97, Laura Lopez Hoffman BA ’96, Brian Enquist (University of New Mexico, Albuquerque PhD ’97, now at University of Arizona, Tucson), and students in my Forest Ecology course (EEB 317).
**Semi-Fractal Geometry of Trees** (started ca. 1985)  This project started when I developed a very simple fractal model that allows a microcomputer to draw a huge variety of tree-like shapes with a few variable parameters that can be measured on a single twig of a real tree. The model is based on hierarchical repetition of a turkey-track, with its parameters being the angle between the toes, the length of the middle toe relative to the side toes, and the shrinkage that the track undergoes with each iteration. The number of iterations is estimated by following a twig back to the trunk of the tree, counting the number of times that the followed branch joins something about its own size or larger. Measurements from various species produced realistic computer trees for about one third of the species. Another third were semi-realistic. One might expect a tree to be fractal if all potential meristems survived, … but they don’t. So the pattern of departure from fractal branching could be a powerful indicator of the “population” dynamics of a tree’s meristems.

**Scaling from Twig to Tree to Global Warming**  I have long studied the adaptive geometry of trees at scales of inquiry from the structure of twigs to the dynamics of the landscape. Now I am trying to translate the results at one scale into the axioms at another. The developmental pattern encapsulated in a single bud unfolds and multiplies to become a tree. The distribution of leaves within this tree determines its rate of growth in sunlight versus shade, and in moist areas versus dry. The growth rate determines a species’ ability to compete with other species in a given environment. Relative competitive abilities are summarized in a table of who grows with whom, and this table can be used to predict the trajectory of forest composition. All of these levels of analysis can be incorporated into calculations of productivity, and they have strong implications for regional differences in the parameters that relate carbon cycling to climate. Progress reports on the preceding four projects were published as: **H. S. Horn, 2000**, Twigs, Trees, and the Dynamics of Carbon in the Landscape, pp. 199–220, in *Scaling in Biology*, J. H. Brown and G. B. West, eds., Santa Fe Institute and Oxford University Press, Oxford, Great Britain.
Wind Dispersal of Seeds

This project started in 2000, at the instigation of Ran Nathan, then a post-doctoral fellow, now an Associate Professor of Evolution Systematics and Ecology at the Hebrew University of Jerusalem. Ran awakened an interest in wind dispersal of winged seeds that had lain dormant since my working with Doug Green (PhD ’80, D. S. Green, 1983, The efficacy of dispersal in relation to safe site density. Oecologia 5: 356-358; also H. S. Horn, 1981, Some causes of variety in patterns of forest succession pp. 24-35 in Forest Succession: Concepts and applications, D. C. West, H. H. Shugart and D. B. Botkin, eds., Springer-Verlag, New York-Heidelberg-Berlin.).

Most seeds fall near the tree, but the few long-distance dispersers are disproportionately important to the maintenance of populations in patchy and changing environments like those that humans habitually produce. The project is collaborative, with theoretical discussions with Simon Levin, episodic advice from Steve Pacala, and meteorological modeling and empirical confirmation by Roni Avissar and Gabriel Katul (both at Duke University). I have designed and built apparatus for the project, namely a “carousel” machine to release batches of seeds under specified wind conditions in the field, and wind jets and strobed cameras to study aerodynamics of falling seeds in the lab. I also suggest experimental protocols to Ran and the Duke meteorologists, using field–informed guesses about the temporal and spatial scale of turbulent, deflective, and convective eddies that are most important for the initial stages in long–distance dispersal, namely: launch from the parental plant, and escape from the canopy.

Seeds must rise to fall far away. An important empirical question is whether seeds that rise in turbulent winds are only those seeds that would fall most slowly in still air, or all seeds that encounter the most favorable winds. Sarah Kaplan (BA ‘01) measured terminal velocities in the lab for tuliptree (Liriodendron tulipifera) seeds that were taken from a tree, from the ground, and from the roof of the Magie-Hibben Apartments in Princeton. The distributions of terminal velocities spanned the same range for all classes (H. S. Horn, R. Nathan, and S. R. Kaplan, 2001, Long-distance dispersal of tree seeds by wind, Ecological Research 16: 877-885). The Duke group, using machinery that I designed and made, and protocols that I advised, confirmed quantitative predictions of the proportion of uplifted seeds of several species in the field (R. Nathan, G. G. Katul, H. S. Horn, S. M. Thomas,

**Turbulence can promote far dispersal** Many novel theoretical insights came from watching and timing the flight of vibrantly painted natural seeds and enlarged paper models. In particular, because the average horizontal wind-speed increases with height within and above vegetation, turbulence at all scales promotes biphasic dispersion of seeds. Those seeds that are retarded in their descent, or even lifted, by updrafts have their range augmented more than the loss in range of those that suffer an equal downdraft (G. G. Katul, A. Porporato, R. Nathan, M. Siqueira, M. B. Soons, D. Poggi, H. S. Horn, and S. A. Levin, 2005, Mechanistic analytical models for long-distance seed dispersal by wind, *Am. Naturalist* 166: 268-381).

**Natural history of launch-sites** I am gradually accumulating a list of qualitatively different mechanisms whereby trees and other plants can bias the release of their seeds toward the most favorable winds. As the list grows, I am thinking about ways to explore each of these mechanisms in the field. But this will happen slowly because the mechanisms involve varied contributions: … from the changing strength of attachment of each seed, from the turbulence induced by a cluster of seeds, and from elasticity of the twig, the branch, or even the whole plant. All our new data and new ideas so far conspire to make long–distance dispersal less rare than traditionally thought, and they set a promising agenda for future theoretical and empirical work, especially on eddies that are coherent over moderate scales of time (seconds to minutes) and space (tens of meters to kilometers). My visual quantification of such coherent wind eddies, using photographs of Christo and Jeanne-Claude’s *The Gates in Central Park*, has gained notoriety for the research (H. S. Horn, 2005, Eddies at The Gates, *Nature* 436: 179; H. S. Horn, 2006, Des portes et des tourbillons, *Pour la Science* 339: 104-105).

**Artificial seeds** I have worked out ways to mass-produce artificial maple seeds to a pattern developed by David Cylinder (Princeton Plasma Physics Lab), and have scaled David’s models up to the size of Silver Maple (7 cm long). Ran has attached mock–ups of radar transponders to these artificial seeds, and to real seeds of Silver Maple, and found that the augmented seeds retain their original aerodynamic properties. Pending funding, we hope to test the feasibility of
harmonic–radar–tracking individual seeds in flight over distances of about a kilometer.

*Wind jets in the lab* I can now simulate coherent turbulent eddies, dropping a seed into a horizontal wind and having it blow along to rise when it encounters a vertical wind. Preliminary evidence suggests that a “helicopter” seed of maple slows its descent (and therefore must be picking up energy) when passing through regions of horizontal wind–shear. This effect might help the seed to maintain station in faster–than–average winds.

Ran Nathan and Gaby Katul have taken the lead in writing results from many parts of this project. A seminar emphasizing my contributions is available as: *Blowing in the Wind: Long distance dispersal of seed with wings, sails, and parachutes* (PPT)

**Cowskin Models**

About 2000 I started a study of a very simple computer model for spatial pattern and competition in plant communities, again awakening an old interest (H. S. Horn and R. H. Mac Arthur, 1972, *Competition among fugitive species in a harlequin environment, Ecology* 53: 749-752). The model itself is a classic that other folks have long abandoned. On a regular lattice, plants synchronously reproduce by tillers, root-sprouts, or locally dropped seed, so that a given site is occupied in the next “generation” by the species that held the majority of the neighboring sites. For two species represented as black and white, and an initially random configuration, the pattern of the community quickly “self-organizes” into something like Holstein cowskin, which slowly simplifies and ultimately may go all black or all white. The intermediate and long-term dynamics of this process have been well–studied, notably by my neighbor Simon Levin and his colleagues. I am more interested in the early transient dynamics, e.g., what level of randomly broadcast seed does it take to destroy either the self–organizing property or a pre–
existing pattern? Preliminary results suggest that low levels of global stochasticity have little effect on either dynamic, … but high levels destroy pattern, and intermediate levels enhance simplification of pattern. Local stochasticity is far more effective than the same level of global stochasticity at breaking pre–existing pattern, but about equally effective at interfering with self–organization. I am sure that these results will be old news in other contexts, e.g., solid–state physics, but their potential implications in the ecology of plant communities would be new. In particular, I find in general that dynamic rules that are good at generating pattern from a random start are lousy at erasing a pre–existing pattern. This weakens a moral that many theoreticians have drawn for ecologists. When a cause is sought for a strong spatial pattern seen in nature, underlying initial or environmental heterogeneity is back on an equal footing with self–organized emergence from a potentially simple dynamic process.

I am interested in extending the model to explore the theoretical adaptive balance between local and global dispersal, empirical measures of how real plants might maintain that balance, and direct measures of cowskin patterns in real plant communities. The modeling already suggests that a simple local measure is correlated with global pattern. This measure is the distribution of number of nearest neighbors who are the same species as a focal individual. In addition to my beloved forests, another promising ecological system for making this measure, and testing the above ideas, is the community of lichens and mosses that grow on rocks and tree–trunks. In addition to being a miniature analog of communities from grassland to forest, the lichen and moss community is a crucial stage in the successional development of more statuesque vegetation on nutrient–poor mineral soil. Accordingly, I am setting out to learn more about lichens and mosses.

Further progress on this project awaits my learning MatLab. My original simulations were run on 8 independent Macintosh SE’s rescued from dumpsters and running overnight as a “Parallel Atilla Cluster.” Their output is a talk: Spatial Pattern in Models and in Sessile Communities (Overheads, soon to be PPT).
Forest Succession

Old Predictions are Confirmed. In the late 1960s and early 1970s I surveyed woods of the Institute for Advanced Study in Princeton and made predictions of forest succession, using a novel dynamic model of the relative age structures of populations of trees (H. S. Horn, 1975, Forest Succession, Scientific American, 232: 90-98). In the early 1990s I found and resurveyed 6 of my 7 original stands. My predictions were confirmed in all but one of the stands. Even in that stand, all predictions that were based unambiguously on the dynamic model were confirmed. The failed predictions involve populations composed exclusively of seedlings and young saplings, which could represent either a chronically unsuccessful input of seeds from neighboring stands or a very recent invasion destined for success. Because the stand was originally dominated by a light canopy of aspen on a sandy soil, I predicted success for those species best able to tolerate drying out, e.g., some oaks and hickories. However, as the canopy matured, less light and less heat penetrated to the forest floor, and as more litter accumulated, the soil held its moisture better. Therefore, maples and beeches, which require more water, were able to out-compete the oaks and hickories. So the outcome is consistent with a broad conceptual theory, yet with a significant contribution from details of natural history. My surveys also permit estimates of standing biomass and productivity. Again I had published inferences about their patterns with succession, and the actual trajectories confirm my predictions.

The data also allow explicit test of a more abstract conceptual model in which changes in forest species’ composition are predicted by multiplying the current composition by a matrix that tabulates which species’ saplings grow well under which species of trees in the canopy (H. S. Horn, 1975, Markovian properties of forest succession, pp. 196-211 in Ecology and Evolution of Communities,
M. L. Cody and J. M. Diamond, eds., Harvard University Press, Cambridge, Massachusetts). Again the actual changes confirm qualitative predictions, and I am currently looking for appropriate statistics to test the quantitative match. Recent results are available as seminars as: *Forest Succession: Predictions and Tests* (PPT).

**Social Butterflies**

For 11 summers between 1973 and 1993 I marked a total of 2,500 butterflies with individual numbers that I could read with close–focusing binoculars. I followed the fates of as many marked individuals as I could for as long as I could find them. I recorded their behavior, made tentative interpretations, and designed experiments to test those interpretations.

I have found that male butterflies of several species recognize particular pieces of real estate, and show tactically adaptive behavior when courting females and repelling other males. These behaviors are superficially as complex and as varied as: random vagrancy, resource–based lek, trap–lining, territoriality, and site fidelity.

[Image of butterfly species]
Nevertheless, their behavior could also be interpreted more mechanistically as a simple consequence of males’ investigating any flying–butterfly–like object, with the putatively adaptive differences being generated by differential behavior of that object. So my current research tries to disentangle the following components of butterfly social behavior: ... a tactical adaptation by the butterflies, an elegant ad hoc mechanism that produces an adaptive effect, and/or an invention imposed by adaptively minded scientists. Significant new insights may come from modeling the mate–searching behavior of some butterflies as the famous “traveling salesman” problem of combinatorial optimization, and making use of some classical “pretty good” solutions, which the butterflies may use. Field work was assisted by Jennifer Horn, Eric Horn, David Horn, Elizabeth Horn, Diane Wiernasz PhD ’83, and Jeff Georgia BA ’78.

**Perceptual Adaptations** The view through the compound eye of a butterfly can be analogized to viewing the world as a blurry scene through a window–screen with hexagonal netting. As the screen moves past regularly structured vegetation, or, closer, over the spotted pattern of a butterfly’s wing, Moiré patterns generate a flicker that can, in principle, encode information well below the intrinsic resolution of the optics of the compound eye. My attempts to model this phenomenon have led to simple algorithms for calculations on hexagonal lattices, which may be of use not only for models of insect vision, but also for models of ranging movements of butterflies over the habitat, and even for models of spatial patterns and competition among neighboring plants.

I used chemical baits and mechanical lures to engineer interactions among Pearly Eye butterflies in the wild. I recorded these interactions with a high-speed video camera. Preliminary analysis shows no qualitative differences in behavior that would necessitate an adaptive interpretation. However it is clear that interactions with conspecific males, conspecific females, and other objects have differing average durations, … and that they expose the focal male to dramatically different visual stimuli. So males potentially possess sufficient information to make strategic adjustments in the duration and geography of a given interaction.

I also discovered that the attraction of a chemical bait can be enhanced by little wind–driven pinwheels, which visually simulate the presence of other butterflies. This is consistent with the notion that males initially search for a locus with a wide domain of attraction, and that a simple visual cue can provide an assessment of the likely number of potential mates. Thus a superficially complex pattern of behavior, analogous to a resource–based lek, can be achieved by a mechanism so simple that it is amenable to controlled experiments in the field.
Population Consequences of Ranging Behavior Those species whose ranging behavior has a large component of “random walk” tend to disappear with constant probability from day to day, while those who hold a territory, trap–line, or mating station disappear at a relatively high rate on day one and at a lower and constant rate from then on. It is as though homesteading incurs a cost either in extensive exploration to find the right place or in an increased probability of death before the territory is well known. I have developed a simple analysis to get maximum likelihood estimates of rates of disappearance of marked individuals, and so I have confirmed the statistical reality of these patterns.

It is appalling to realize that the only publication from all my butterfly work so far is a brief technical note: H. S. Horn, 1976, A clamp for marking butterflies in capture-recapture studies, Journal of the Lepidopterists’ Society 30: 145-146). A seminar is available as: Social Butterflies: simple rules, complex behavior, and population consequences (PPT).

Regional Natural History of Princeton

Video Surveillance of Wildlife (started 2005) I aided the set–up and trouble–shooting of a video system for wildlife surveillance at Princeton’s Stony Ford Center for Ecological Studies. I gathered preliminary data and did initial analyses of movements of White–tailed Deer. These were extended and expanded in Senior Theses by Brendan Williams ’06 and Kristen Arnold ’06 (both co-advised with Dan Rubenstein). Brendan’s chief result was that simple patterns of ultrasonic signals were ineffective as long–term deterrents of deer even though the deer were initially startled. Kristen mapped deer trails in the vicinity of the video system, and discovered that trail use and browsing intensity were generally correlated, but that some heavily used trails were, like interstate highways, used mainly for non–stop travel. A project for the near future is modifying the video system for studies of winter foraging flocks of birds.

17-Year Cicadas (2004) During the 2004 local outbreak of 17-year Cicadas, I designed a tuned resonator for a commercial sound pressure meter, and used it to map the intensity of male Cicadas’ chorusing over the Princeton Campus and vicinity. My identification of specific chorusing centers contributed to 2005 Senior Thesis research by Uta Oderdürster (advised by Peter Grant: U. Oberdürster and P. R. Grant, 2006, Predicting emergence, chorusing, and
oviposition of periodical cicadas, *Ecology* 87: 409-418) and Marian Bihrle (advised by Martin Wikelski).

**Herpetology** On 11.April.92, at the behest of James D. Lazell, President of the Conservation Agency, Conanicut Island, Rhode Island, I organized an expedition to search for topotypical material of the Northern Slimy Salamandar, *Plethodon glutinosus*, originally described from Princeton, NJ in 1818 by Jacob Green. When I turned over the rock that uncovered the definitive Topotype of this important species, it took me back to my days as a larval herpetologist (*H. S. Horn, 1969*, Polymorphism and evolution of the Hispaniolan snake genus *Uromacer* (Colubridae), *Breviora of the Museum of Comparative Zoology, Cambridge, Massachusetts*, 324: 23 pp.).

**Forest Conservation in and near Princeton (started ca.1970)** I have worked vicariously through two seniors, Jackie Lu BA ’99 and Lisa Gomes–Casseres BA ’99, to extend studies by several other students (especially Karine Thate BA ’98, and Dunrie Greiling BA ’92) documenting historical spatial patterns of deforestation and reforestation in Princeton and adjacent townships. These data are crucial to planning human development that is consistent with, or at least not catastrophically disruptive of, conserving local biological diversity. For his senior thesis, Ted Floyd (BA ’90) made a census of all breeding birds in the Institute Woods. In marked contrast to other studies, he found very little evidence for species’ either preferring or avoiding the edge of the woodland. He also found a deficit of forest interior species relative to other studies of suburban forest “islands” of comparable size. The chilling inference is that local forest fragments may be doubly depauperate, once for their small size and again for their isolation. My only contributions to Ted’s work were discussions of technical measurements and of over–all interpretations.

About once every decade I give a presentation on this work to the combined *Princeton Township and Borough Planning and Environmental Commissions*. Afterwards some Commissioner invariably comments, “This was a wonderful eye-opener. It’s a shame that you weren’t around ten years ago when we were setting the current trajectory.” The latest version of the seminar is: *Princeton Township’s North Ridge as a Natural Environmental Unit* (PPT).
Guide to Observing and Teaching Local Natural History (first culmination 1996)
With the help of eight elementary teachers from nearby school districts, I wrote a guide to local natural history and natural areas, with proven suggestions for outdoor class activities. While this is not in itself a novel piece of scholarly research, it embodies the results of many original projects by me and by students whom I have sponsored, including floral and faunal surveys, measuring trees and counting annual growth rings in extracted cores of wood, finding old maps and aerial photographs, and using that information to suggest the history and prospect of the landscape.

The latest manifestation of this work is a teacher’s resource CD-ROM, The LiWA Visit N.J.: 450 Photos of Little Wooden Animals & Core Curricular Ideas, 2008. The LiWA are pictured overlooking objects or scenes in New Jersey that invite ecological interpretation. The images are accompanied by local interpretive notes and suggestions for how the images might be used in children’s exercises that combine reading, writing, math, science, art, and history.
Biomechanical Assistance for Paraplegia (1975-1987)

Our son, Eric (b. 1973), had a congenital lesion that even after corrective surgery left him “not a candidate for functional ambulation.” My inventions and adaptations bought him 11 years of high mobility with crutches and braces, and may have fostered his current mobility and independence with a wheelchair. The home–made machinery included: allometrically scaled walking frame and crutches, tripod and stair–climbing walking frames, counter–adduction skids, and elastic shoes. I also designed a novel (at the time) analysis of catheterization records that evaluated bladder function non–invasively. Studies by several undergraduates were helpful: Andrea Wilson BA ’85, Randy Peters BA ’86, and Meg Doherty BA ’87. Eric and I hope eventually to record and publish our experiences, but first we have to fulfill our responsibilities as philosopher (Eric) and ecologist (Henry). Until that day, the only public form of the story is a seminar that I can give: *Paraplegia: a Case Study in Amateur Bioengineering* (PPT).