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AN INSTITUTE FOR THEORETICAL ECOLOGY? PART IV: "COMPUTATIONAL WORKSHOPS": A PLANNED ACTIVITY FOR THEORETICAL ECOLOGY[1]

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Abstract. Part IV of the five part series on Theoretical Ecology presents a description of a new model for conducting analysis and synthesis across broad realms of environmental data. This new workshops model, referred to as "Computational Workshops", emphasizes the full use of ecological data in testing hypotheses and making environmental decisions. This workshops model is presented as a primary activity for a proposed "Institute of Theoretical Ecology". Part I of this series (Conley 1990) provided a definition of Theoretical Ecology. Part II (Conley 1991a) provided both a critique and a discussion of proper design of large inter-disciplinary "Centers" that focus on a broad discipline such as Theoretical Ecology. Part III (Conley 1991b) presented an argument for the desireability of such an institue. Part V (Conley and Brunt 1991c), provides increasing detail on some of the activities and methods that would enhance the chances for success of this institute.

1. Data-driven problem solving

The purpose of having computers in a research laboratory is that they provide leverage for increasing the amount of work that can be accomplished. Just as the mechanical age of the 19th century allowed mankind to increase the power of human muscle, computers offer magnification of the human mind. As programming environments gain sophistication, computers are increasingly being used to solve complex one-of-a-kind problems in addition to the traditional performance of repetitive tasks.

While it is true that computers can grately increase the efficiency and power of our approaches to understanding complex problems, they also provide excellent opportunity for wasting time with technological trivia that has little to do with the problem at hand. What we should be doing to improve our approach to seeking answers to ecological questions is to watch what people (in this case, ecologists analyzing and modelling ecological data) do when they solve real problems, and then provide a computational and physical environment that is supportive rather than intrusive and dictatorial.

The Computational Workshops model addresses 2 problems: (i) how to achieve a synthesis and blending of ecological data that ends up being more than a simple sum of the parts; and (ii) how to capture the understanding of techniques and methods that really do work, so that the infrastructure supporting the work can grow to be better than it is at present. What we need then is a working computational environment where ecologists solve real ecological problems. As this activity succeeds in producing advances in ecological understanding, the general ambience that encourages this success should be studied and improved. Thus, I am advocating studying the process of achieving good ecological science, as well as the conduct and pursuit of the more strictly narrow scientific goal of testing ecological hypotheses.

This discussion emphasizes cooperative computational approaches to ecological thinking. The "Computational Workshops" described are designed to support small research teams who have some data and some questions to attack. We want this group to do this work together so as to focus their combined intellect on a common set of data and some general questions. One of the ways to recognize successful work of this sort is if the group is able to blend and work the data into common analyses, rather than simply discussing graphical representations of the disparate data sets. Such work done well is suprisingly difficult to obtain. Group interactions among people provide recognizable behavioral patterns that are both positive and negative. We must learn what a computational environment needs to be like to encourage the positive aspects and then design one that supports such work. We must also come to know what the physical and organizational environment should be like.

The general thesis of this approach is as follows. Assume that you have present a group of cooperating

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researchers ready to work on a topic of common interest. Assume further that you have assembled a significant amount of the available relevant data. This will generally mean that the participants will have contributed data from their own research, and also that they have obtained documented data from other relevant sources. The goal of the Computational Workshop is to answer several a priori questions, and to let the creativity of the group extend to possible emergent hypotheses that can be tested. You have the data and the computational abilities at hand, and so you attack the questions and hypotheses. Now assume for example, that Participant A says that the relationship between X and Y is (say) positive, and Participant B says negative. In the course of such efforts, there are only 4 logical possibilities to be considered. These are as follows:

1. A is correct, and therefore B is wrong;
2. B is correct, and therefore A is wrong;
3. analysis of the data demonstrates that the relationship between X and Y is zero (and you have data of sufficient quality to warrant this conclusion);
4. the group lacks sufficient data to test the hypothesis and answer the question to the groups' satisfaction.

In an ideal world, this procedure would result in conclusive results based on the data 3 out of 4 times - only in the fourth and final case is it justifiable to argue that there is a need to conduct additional experiments or data collections. This approach to ecological questions makes the very most of the expense and effort devoted to data collections. The extensive amount of ecological and environmental data being collected by various governmental agencies as well as by research scientists would thus be brought to bear on the questions.

To be sure, there will be quibbling over methods and techniques, appropriate data vs. inappropriate data, good data vs. bad data, and exactly what the documentation (if any!) for the data implies. This simply means that the real world is not ideal. In either case, however, I submit that the effort devoted to seeking answers to many high level and integrative ecological questions would be greatly repaid by proceeding in this manner. If a question can be answered definitively by some innovative use of unconventional data, then there is no need to collect yet more data. If the forth case prevails, and the question cannot be answered, then the effort devoted to the analysis and working of the available data would serve to focus subsequent work that might be attempted. Either way, the level of ecological understanding is increased. This process maximizes the exploitation of available data before additional costly field collections are undertaken.

It is not particularly difficult to demonstrate that this model is not the current approach to ecological issues. The general trend in biology is to collect data. Scientists are good at collecting data. The recognized products of science are written statements that define and then solve a problem. Such statements present relevant theory and data analysis that applies to a solution of the problem. When the volume of data is great, data management and analysis can be surprisingly difficult and time consuming. Long term management of ecological data is not a well developed activity, and it is expensive. Although the problem of data manipulation is difficult enough for a scientist working alone, for scientists working in small research teams, the cooperative problem is quite imposing - so much so that much of the work that might otherwise be done is never attempted, and much of the relevant data that might be used is never applied to the questions.

In the fast-moving scenarios present in modern research laboratories, our ability to collect data far outstrips our ability to realize the full potential that archived data offers for understanding natural phenomena. It is a rare data set that is analyzed more than once. In the course of such things, research data are collected, analyzed for answers to the question at hand, and then put on the shelf - typically to be eventually discarded.

This cycle is unacceptable. Data collection is expensive and difficult. Proper documentation and maintenance (archiving) of data makes research even more expensive. The growing awareness of the value of long-term studies makes data management even more critical and expensive. The general feeling that data are good only for the questions posed when they were collected is being challenged by the recognition that such data should be of further use for other purposes. Documenting a data set implies sufficient commentary so that future researchers who did not collect the original data can know when it might be appropriately used and when not.

The primary products of most research projects are the data that are obtained. While some research fields have developed a serious ethic for managing data and providing suitable documentation, others have not. It is not the purpose here to berate and detail this problem, but rather to recognize it and to seek solutions for archiving and using data that are known to work.

The fundamental thesis of this philosophy is that scientific research teams will be more innovative and productive when presented with a proper computational environment and all of the relevant data, and that teams of researchers can demonstrate emergent properties not associated with individuals. While support for individuals is necessary, an environment that supports a research team must be designed to accommodate the extra requirements imposed by the group interactions. In order for research teams to have access to data to work with, there must be accommodation of what they want to do with the data, and support for doing it fast.

Fast is, of course, relative. The implication in this new workshop model (referred to here as "Computational Workshops") is that analyses and results must proceed at such a speed as to capture the attention span of a busy group of scientists who are engaged in the business of solving a problem together. If you have to wait 2 days for the programmers to get an answer to a question, you will probably forget why you wanted to know. If answers to questions that require data and statistical analysis and modelling are too difficult to obtain, the group will be relieved to get any results, and will tend to stop before a really thorough job of analysis is accomplished. If you are trying to compare results from various algorithmic approaches, you need all of the possibilities at your fingertips if you are to be fully successful.

Pressing environmental and ecological problems of the day are too imposing to attack in such a superficial manner. Computational environments that support military decision analysis are quite sophisticated and supportive. Similarly, decision analysis in industry is currently supported by major research efforts in both academic and industrial laboratories, and the products of this research are being increasingly used in boardrooms and engineering laboratories around the world. In contrast, decision analysis in ecological research laboratories remains largely in a computational Bronze Age. There is little available support for researching questions of group productivity among ecological research scientists. Nor is there much interest in research designed to understand what ecologists really need and would really use in the way of computational support environments. The need is thus for an understanding of this process, for a working model of team dynamics as the group handles large data sets and complex questions, and for a computational environment and philosophy of use that is people-oriented and that works to solve real problems.

2 Product-oriented workshops

"Workshops" that address specific questions are a common means of group work in ecology. The typical workshop consists of people who gather from near and far to talk about a problem. This approach usually entails individual presentations to the group, often supported by offerings of previously accomplished data analyses. The analyses presented usually are of that participants' site, and they are, of course, intended to support a particular point of view.

In this typical workshops approach, the intent of the discussion is to convince the group that your idea is the right one. Strong personalities can dominate, and the group can come to exactly the wrong conclusions for reasons that seemed right at the moment. The discussions are driven by prepared graphics and analyses intended to make a point. Because the raw data that generated these results in the first place reside at the home institutions, attempts at further analyses to blend and merge cross-site data must be left to later work. Sometimes such work gets done and sometimes not. The typical products of such workshops might be a collection of contributed papers, or a "report" that extols the virtues of the exchange of ideas, often with conclusions that are to be written at some later time. Even if the group does arrive at some new questions and some new analyses to conduct, they must postpone such efforts until they return to their respective laboratories where the data and computational support resides. Thus, rather than a true synthesis of cross-site characteristics, we get a collage of results that does not involve merging the cross-site data sets for a true blending and analysis of the available information. This means that nothing really new is likely to emerge from the workshop efforts.

In contrast - and considering that the goal is to obtain a full and deep analysis and synthesis of available data - imagine the following scenario taking place at a research laboratory called, for purposes of discussion, "/.intersite[2]".

- A site exists that specializes in organizing and supporting Computational Workshops where analysis, synthesis, and modelling of data is the business to be accomplished. This site knows how to:
  - organize a Computational Workshop with a team of researchers who have an ecological hypothesis (es) and some relevant data;
  - download the appropriate data from participating sites, and get it installed in a computational environment that is specifically designed to support the fast-paced cooperative work of the group;
  - work with the research team during the lead-in, the Computational Workshop itself, the wrap-up of the analyses, and the final production of manuscripts or other documents.
- A group with questions and hypotheses relating to an existing data set begins planning for a Computational Workshop. The products of the workshop may variously be intended as a manuscript, a poster or paper for an upcoming meeting, a proposal, a final report, or any similar product that represents a scientific conclusion drawn from the available data.
- A research assistant or PI on sabbatical (etc.) takes up residence at /.intersite for a time suitably ahead of the Computational Workshop to conduct descriptive and preliminary analyses and to prepare for the workshop. /.intersite staff provides the

2. The symbolism is taken from the UNIX "dot" files. Such files are typically unseen, and provide background information and support for user activities.

necessary training and help with the computational environments and the philosophy of the Computational Workshops.

- Participating data sets from the various sites are documented and installed in /.intersite formats. If participating sites are already using the /.intersite Archives File formats, this procedure is automatic and easy to accomplish (if not, this aspect of the workshop may well entail the most effort of all the activities). The generalized /.intersite Archives File format makes all of the data and coumentation available for subsequent rearrangements and selections to provide subsets of the information for further consideration. In practice, this means that any of the data can be arranged in any descendent form for analyses and testing of new ideas that arise during the course of the workshop.
- A statement of the goals of the workshop, the questions, the relevant data, and the products expected is prepared. Preliminary analyses are conducted and organized to send to the Computational Workshop participants. These preliminary results are intended to provide background for the synthesis effort of the workshop. The notebooks to be sent might include such materials as descriptions of all data, descriptive statistics of the data sets, preliminary graphs and brief discussions (perhaps in the form of extended captions to the figures), and an explicit statement of the questions and hypotheses posed. These notebooks can be quite extensive, and are intended to familiarize all participants with all of the data (where otherwise each would typically only be familiar with their own data). These materials should reach the participants some weeks in advance so that they can study them and comment on the directions of the pending workshop.
- This preliminary work also includes building summary analyses of the data. This is particularly important when dealing with large volumes of raw data that may require specialized processing for summarization. The goal is to synthesize across sites, not to produce detailed descriptions within sites. Statistical summaries of the data will be much more useful in this regard than the raw data.
- Participants arrive at /.intersite and are given preliminary instruction on cooperative computing and the group approach to workshops. Arriving participants will find that the preliminary analyses are organized and displayed on bulletin boards installed in the computational laboratories of /.intersite. Lots of blank spaces exist for additional development of such displays during the course of the workshop.
- The workshop proceeds through a series of questions posed before the meeting, assembling and conducting analyses and graphics that add to the preliminary work, and that present the results for all participants to ponder and discuss. A heavily annotated outline with graphs and tables begins to take shape on the bulletin boards.
- As the planned analyses proceed, questions that could not have been anticipated before the workshop begin to emerge. The power of /.intersite's computational environments is demonstrated as the staff and visitors alike tackle the new questions and let the excitement of the moment guide the work.

  It is this emergent property of the Computational Workshops that makes them extraordinarily productive. Because the data are readily available, questions that were not anticipated can now be immediately addressed. The activities of the Computational Workshop iterate between discussions driven by the emerging analyses being displayed on the boards, and work on the keyboards, seeking the answers and patterns from the data. The course of the workshop is guided by a data-driven scenario where each conceptual step taken is tested against immediate analysis and modelling of the available data.
- If questions arise that require data that had not been anticipated, it may be possible to access data bases at /.intersite itself ("left over" from previous workshops) or at any participating remote site and bring it into the workshop. The /.intersite format conventions now come into full play, and make this effort possible without the requirement of unavailable amounts of time and effort.
- As the workshop proceeds, current accomplishments are represented by production of results of the analyses. These can be made available in the form of tables of data, and of plots and charts in presentation formats suitable for publication. Writing of captions for the figures and tables, and of manuscript sections such as Methods and Materials, and preliminary outlines of the Results can be accomplished during the Computational Workshop.
- As the Computational Workshop draws to a close, the following products are to be expected depending on the original intent of the meeting.

  Poster: The poster can be completed during the meeting including presentation graphics and discussions, and put on the boards as a dress rehearsal.

  Manuscripts or Proposals: A heavily annotated outline containing Tables and Figures, along with sections designated for various participants to complete the writing. The /.intersite staff can facilitate the electronic communication required for full participation of all members of the group.

  I. Graphs, Tables, and Literature Cited: Figures and Tables can be completed during the

Computational Workshop if the analyses are judged complete and tested for correctness. Bibliographies can be roughed out using lists left from previous manuscripts, and installed in appropriate data bases. Other citations will need to be searched and keyed.

II. Graphs, Tables, and Literature Cited: If the analyses are tedious or particularly complex, there should be a period of wrap-up to complete and perhaps redo the analyses conducted in the heat of the moment during the workshop. This work is conducted by the same person who arrived to set up the workshop, aided as needed by /.intersite staff. Checking the analyses to make sure that the proper data were used, and that the analyses were properly set up is essential.

Tested Data Sets: The Computational Workshops will also result in assembled and tested data sets relating to various ecological phenomena. These data sets have been exercised during the course of the workshop, and represent a valuable resource for future work. These data sets are to be fully documented, and can be ported back to the home sites of the participants or (given consideration of ownership) to other interested researchers.[3] Note that this product of documented data sets provides a valuable resource for future work, and it preserves tested data sets that are impossible to regain if lost.

Code and ALgorithms: If the workshop required development of unique algorithsm, models, or special analytical techniques, these results can be captured, documented, and made available to the research community. Thus, the wheel only gets invented once in each instance, and the discipline can devote its' efforts to new solutions.

- The final document is written and produced. This can be accomplished remotely with the help of /.intersite for communication and for support for remotely located group writing. Alternatively, /.intersite can help port the text and related materials to participating sites for use in any manner the participants might choose. In the usual course of such things the senior author takes responsibility for directing the writing and assembling the final manuscript.

This model for conducting Computational Workshops places the emphasis on doing much of the work at the workshop. It is a product-oriented approach that seeks to capture the intuition and understanding of the moment. In this manner, many analyses and models may be tried in a relatively short period of time. The ability to address emergent questions that could not have been anticipated before the workshop provides a potential that is not found in the traditional workshop model, where the goal tends to be convincing argument rather than creative explorations of the data.

Combining the integrative powers of the Computational Workshops model for cooperative computing, with research sites that are conducting related experiments in field and laboratory, provides significant support to the iteration of the theory-experiment cycle. Each of these aspects of addressing scientific questions are better when done together than either is when done in isolation.

3 A brief phychology of small-group dynamics

This topic deserves a more complete discussion, but to do so would put the length of this paper beyond what is possible at this point.

In order for the Computational Workshops as described above to be worthwhile and productive, it is necessary that the hosting group be aware of some important aspects of small-group phychology. A basic rule of thumb is to limit the number of participants in these sessions to about 6-8. When group size goes over about 8 funny things begin to happen to the discussions, and the real work of the sessions is often subverted by extraneous posturing. The task of limiting the size of the group is tougher than it seems because people end up excluded and feelings get injured. The obvious solution here is a continuing program that supports enough workshops so that there are enough opportunities to go around. Lacking that, we have been promising people that the pending workshop they are interested in is not the last of its' kind... We hope.

Proper group size depends on personalities. For some people the best group size is one. Even if the participants know each other, expect that it will take a day or so to get used to the capabilities and operating mode of the Computational Workshops. There should be some preliminary time for participant ''posturing''. Schedule some loose time at the beginning for participants to establish their own status and professionalism to the group. Once the credentials are presented and the proper respect is gained, the scientific exchanges to follow will go much smoother. Offer introductions and get people to talk about

3. Note that there is no intent for undirected assembly of random data sets. The data sets that result as products of the Computational Workshops are those that were assembled and tested for the purpose of the questions and hypotheses of the workshop. These data sets will provide an invaluable resource for future work because they have been thoroughly tested in the most rigorous manner available - that of a group of experts actively and critically going over every aspect of the data. As the number of such documented and tested data sets grows, so will the potential that they may be used for yet other syntheses of information.

themselves and their work to break the ice. Scheduling sessions where people make brief informal presentations to back up the preliminary materials in the notebooks sometimes works. Be careful with these presentations - if they are repetitions of the notebook materials they will be boring; if they are simply pontifications for the gratification of the speaker they will be a dash of cold water to the group. If they are too long they will take up time that can be better put to actually doing some work with the data. All of this is especially important when all participants do not know each other, but necessary even when the group ranges from casual to close acquaintances.

This introductory effort also means that you will want to schedule some busy work for the start of the session, and pose a few questions that you know you can answer (you might even practice on getting a few answers beforehand). By demonstrating as a host group that you can respond to questions of the data, and can produce results as tables and graphs, and as ephemeral screen views or hardcopy, the working group becomes confident that they are free to pose questions, and they will have at least some likelyhood of seeing some answers. In small groups this awareness can be developed in a day or two, in large groups, the interactions can be so disruptive that you never reach this important threshold. In Computational Workshops where the participants have been through this exercise before, the preliminaries can be brief and you can get right down to work.

There is a fine dividing line between too much leadership and too little. If you are too autocratic and rigid about the tasks of the workshop, then people will lose interest. Conversely, if you fail to provide some leadership, the anarchy that results will seriously limit the potential to address even the planned questions. In this regard, it is probably better to start out with fairly heavy handed leadership and lots of structure, and then to let attentions be guided by the emerging discussions as the workshop proceeds. As this begins to happen, the leadership and organized structure can become less obvious.

The Computational Workshops emphasize group work on the questions, and de-emphasize people telling each other what to do or presenting lectures. The Computational Workshops are not conferences where individual papers are presented to the group. The sessions are designed to encourage seeking answers from the data. The preliminary notebooks are intended to provide needed information and to avoid too much talking about the work. If you have the data at hand and know what questions to address first, then cut to the analyses and drop the discussions. If you lack the necessary data, then drop that point and move on. Essentially, this means that if you cannot resolve a quibbling session by conducting a hard core data analysis, then you don't have the data resources to resolve the issue and you need to get on with something else. (It is possible of course, that the something else you need to get on with is designing a future proposal or experiment, and that this could well be the topic of a future workshop).

Dominant personalities can drag the workshop astray. Clearly posed a priori questions and goals will help keep things on track. If you are too restrictive and narrow, then the emergent properties of the session are likely to be lost. Certainly people will lose interest if you are dictatorial. Conversely, you will need to be strong with people who are simply disruptive. If they have not done their homework, or have failed to be prepared for the workshop, they will feel left out and will try to guide attentions to matters they may know more about. Use the group to control this behavior, relying on the overall wisdom of the group to keep things more or less in focus. When things began to break down, as they will on occasion when people get tired and need time to think, bring in the beer and pizza, and take time for a run or a swim or some kind of attention diverting activity. The group will return to the questions of the day soon enough if things are going as they should.

It is often useful to separate into small groups to explore tangent questions and analyses. These subgroups can then come back with the results when they are ready. If you have a problem personality who demands to do it their way, then accommodate that person - isolate them with their own machine and let them work on their particular problem and bring back the results to the group when they are ready. They will soon choose to rejoin the working group if things are going right.

Make sure you have agreements on how the writing and authorship line will go. It is unfortunately true that there cannot be 2 or more "first authors" on a manuscript. Someone has to take charge of this issue. In our labs, the person who writes the first draft of the manuscript is the first author, and will guide the writing and fixing through to completion and submission. This incentive gets some first drafts done that would otherwise go unwritten. There is precedent for a footnote that indicates the extent of the equality of all authors, and this might also be appropriate under the right circumstances. Keep in mind that no one ever lost a friend by putting their name on a good manuscript. It costs you nothing to add authors, and in the spirit of the workshop, this remains an essential ingredient for continuing success. There will always be uneven contributions and effort in any group endeavour. This has no effect on the products of the workshops. In subsequent workshops, people who really do contribute tend to be invited back, and those who simply watch from the sidelines tend to be left off of the participant lists.

The Computational Workshops are best when they run up to about 5 days. The sessions become quite intense when they are going right, and people will get tired. Schedule some daily peripheral activities that allow people to lighten up a bit. Make the laboratories available on a 24 hr basis for those who desire to keep at the work, or who get onto something and want to see it through. Avoid all-day field trips that are exhausting in themselves. Avoid large scheduled formal dinners that lock the participants into a long drive to the restaurant, and then further lock them into fixed positions around a table where they must talk to the same couple of people on either side for the entire evening. The trick here is to schedule some activities that allow people to continue the discussions and the science in different settings where their attentions are not completely disrupted from the goals of the workshop. You may well generate some ideas at such "recreational" activities that people will want to pursue through the night. Leave this as an open possibility.

Stamina is a factor in these Computational Workshops. If things are sufficiently free flowing, people will come and go as their energy and enthusiasm allow. In the Science Workbench laboratory (see Conley et al. 1986, Slator et al. 1986), we have never succeeded getting a written draft of a manuscript completed at one of these Computational Workshops. By the time you get enough material and structure to begin writing, people are becoming tired. You cannot push people to writing under such conditions. You can, however, work to get a heavily annotated outline of the paper completed. Work to get all analyses, tables, and graphs completed, or at least in preliminary form. Details of final presentation are not essential for consideration during the short time of the workshop, and should be left to later. Organize the outline, tables, figures, and commentary, on the bulletin boards of the laboratory, and work to get a final structure for the paper. Try to get volunteered assignments for writing of the various sections of the paper. Any of this you can get done at the workshop will increase the chances that you will actually have a submittable manuscript in the near future.

Keep in mind that hosting a productive Computational Workshop is an art in itself, and that you can learn how to do it better. There is no final prescription as yet for just how to accomplish this feat. If we are successful in establishing several sites that choose to specialize in this kind of scientific activity, then, with the experience of repeated efforts, we can expect to learn how to do this job better. As we learn, we will be increasing the infrastructure support for Theoretical Ecology. We will also be demonstrating that this new way of seeking answers to some ecological questions is producing results.

4 An overview of the computational environment needed

Although it is possible to envision a computational environment that is specially designed to support the workshop model described above (Conley, ms; Conley et al. 1986; Slator et al. 1986), such a specialized environment is by no means essential. The key requisite is that the relevant data reside locally in a suitable data manipulation system that can offer rapid assembly of desired subsets of information. In modern computing environments, this implies a relational data base system that is flexible enough to allow interactive command-driven queries, and that produces descendent data structures that can be picked up by the statistical and graphics applications that will be used.

Given such manipulations, you then need a command driven statistical package that includes graphics, and a plotter and a printer. Statistical systems that require programming take too long to produce results, and will be less useful for these sessions. While formal inference statistics are useful in these sessions, you will quickly come to appreciate a highly interactive exploratory statistics package that emphasizes lots of graphics and multiple views of the data. Inevitably, if the applications package that you are using does not allow extensions for unanticipated analyses, you will arrive at a point where the group wants an analysis that you cannot produce. Some statistical packages support this kind of work and others do not.

Test your host group to find out if you are adequately prepared and equipped to perform these services. Bring in a substantial amount of data from several locations and install all of the information, including documentation and comments in your archives and data base system. Create chosen subsets of data that are taken from all available data, and make graphs on the terminal screens. Also make some hardcopy, both on the printer and by plotting 2 or 3-dimensional graphs of various attributes. Conduct various statistical analyses of the kind that are appropriate to your subject. Then capture the results of those analyses, and build new tables and graphs of the new information. You should be able to plot and print any subset of the data and in any format that members of the group might request. Take these results and put them back into your data base system for further manipulation. Take the tabular results and assemble them into an annotated outline that you can format and print during the workshop. Include the graphs in the physical assembly of the manuscript. Assemble the annotated outline for the growing manuscript on the bulletin boards, in the same manner that you would assemble a manuscript that is being readied to send to the editor of your chosen journal outlet. If you can do these manipulations on the data and on the results of the analyses in "real time" than you can successfully host a Computational

Workshop. Real time in this context means while someone who requested the results is standing at your shoulder watching you get the results, and who can then carry those results back to the group to continue discussions. This means that you must be able to produce results sufficiently fast to maintain the interest and attention of the group. Some tasks such as those requiring programming or remote computers will take longer, and the group might proceed to other questions while this is being done.

If the available computational environment is designed for individual instead of group work, then you will want some experienced computational specialists around to do the bidding of the workshop participants. You may want this in any case, since it is often not reasonable to expect visitors to be sufficiently familiar with local computing support to be useful on the keyboards. One way to approach some of these problems is to develop a laboratory that contains a variety of MS-DOS and MacIntosh computers, along with the more powerful UNIX workstations. Network connections then make mainframe access possible, as well as computers in remote laboratories that may contain some installed software that the group wants to use. If you have some programming specialists available, then it is often possible to work up some quick prototype code for an analysis that you had not anticipated when the workshop was organized.

The laboratory spaces should be comfortable and supportive. You will want a lot of bulletin board space to organize the emerging results of the workshop. Conferencing areas, work spaces, and lots of keyboards are essential. Several small rooms have worked best in our experiences, however, the possibility that a larger room can be partitioned by clever arrangement of the furniture should also be considered. Expect that some participants will want to work through the night, and can be accommodated by providing food and as much comfort as you can arrange.

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