Practical Methods for Measuring Human-Computer Interaction

by S.W.Draper

These notes were originally created with a lot of help from Keith Oatley, as part of a project creating teaching materials for HCI with Keith and me together with Phil Gray and Alistair Kilgour.

Introduction

Opinions and ideas in HCI often begin with personal experience: of frustration or enjoyment at an interface, or of seeing something happen to someone else. To take the next step beyond this requires gathering more observations in order to give one's opinions and ideas a wider and more solid basis. For instance, you might ask several people to try the same task on a given machine and time how long they took, or count the errors they made. Or you might ask several users the same set of questions, and compare the answers you got. This is simple empirical measurement of the performance of human interaction with that machine or program, and it is our subject here.

To see what is involved in general, it is helpful to think of an analogy with an electronics technician's workshop (which we discuss further below). Various instruments are widely used (e.g. voltmeters, oscilloscopes), though the way they are used and what they measure depends on the particular task being addressed: the same methods are used for a range of objectives. We shall discuss these ranges of measures, instruments, and objectives, and how they relate to each other.

What follows is really only an introduction to all that might be said on the subject of measuring human-computer interaction. It is worth studying however, because even doing small amounts of actual practical measurements can both greatly benefit the project you are working on, and also give you a feel for what such methods might be good for. This is useful if you wish to contract others to do more of such work for a team you are part of.

We are here concerned with empirical measurements — not analytic methods for predicting the performance of a design, such as GOMS or TAG. Although analytic methods hold out the promise of being faster, cheaper, and do not need the design to be already implemented, there is no sign yet of their being able to predict performance in a practically useful way — HCI theory is still far short of being predictive. In any case, developing and checking such methods requires empirical measurements.

In HCI the iterative prototyping cycle is fundamental. One step in that cycle is that of observing the interaction between users and some version of the design. The methods described here can be used for that, and this is one important reason to study them. However they may also be used for other things: for instance for comparing two commercial products. Such activities are often called "evaluation", but the methods described here are best described as practical methods for human-computer interaction measurement: firstly because they can be used for other things than value judgements (e.g. detecting bugs), and secondly because other non-empirical methods (e.g. analytic methods) are often described as evaluation but are not dealt with here. These measurements are, strictly speaking, measurements of the performance of the combined system comprising a human user and a machine (usually a computer program): of system performance. One could use such measurements to report on how well different users perform compared to each other. However here we discuss measurement only from a user-centered viewpoint which takes the attitude that all problems are problems in the design of the machine, and in particular of its user interface.

The term "evaluation" has been widely used, but implies too narrow a view. "Evaluation" refers to a goal; measurement is more basic — part of the means to a number of alternative goals. Such measurement is a skilled activity in its own right, that can usefully be considered as a separate subject. Putting this another way, we can say that evaluation properly has two parts. One is measurement. The other is assessing measurements in relation to goals.

We shall begin by developing these introductory remarks into a conceptual framework for thinking about measurement in terms of five stages, each with properties that affect how you would make the choices involved in carrying out a measurement study. We shall then deal with each of the five levels in turn. We give a brief discussion of measures, then describe seven basic instruments — this is much the largest portion. Next, we deal with testing episodes, then the calculation of results, and finally we will discuss the reports that an evaluator might make.

Measurement Framework

In general, we think of interface performance measurement as involving the following issues. First there is the issue of what **measures** are taken, e.g. time to learn, user attitudes, errors made in doing a particular operation. Secondly there is a choice of **instrument** for making the measurements. In fact instruments are often best used in combination to form a **testing episode**: different combinations are used in different cases. Then the **results** are summarised or calculated, perhaps using statistics. Finally the conclusions are **reported**.

These choices can be summarised as:

Measures —> Instruments —> Testing episode —> Results —> Report

Besides issues of what to report and how to present it, often an investigator knows a lot about what is wanted — the real purpose of the study — and uses this to make the choices about measures and instruments. Finally, there is the issue of **theories of HCI**. A general theory would predict what factors or features of the system and the testing situation determine the measurements observed. Theories thus tell you what measures might be worthwhile. Measurements are more general than theories — that is why they can be used to test theories. Nevertheless you can't measure everything all the time, so theories are influential in deciding what measures to attend to, and what features of an interface to change in order to try to improve the values observed. Here, however, we aim only to present seven instruments and how to use them — but not to present any theories about what values to expect to observe in particular cases.

The techniques of measurement we recommend are like a set of instruments on an electronics work bench: meters for measuring voltages and currents, oscilloscopes for inspecting signals, devices for testing pieces of hardware. They are indeed psychological instruments, and they measure aspects of the goals, plans, actions, and knowledge of a user interacting with an interface and the information flowing from it. In any design or evaluation process these need to be used in particular ways at particular points. Often several instruments will be used together in a single testing episode: for instance you might set up an experiment but give the subjects a questionnaire before, and interview them immediately afterwards. Thus a user interface together with its application program are like an audio amplifier and speakers; the task set the user is like a signal generator; the instruments (e.g. questionnaires) are like meters; the measures (e.g. satisfaction, or time to achieve the task) are like the quantities measured (e.g. voltage); the testing episode determines additional conditions such as the available help for users, or the temperature and power supply for electronics; the report generated after analysing the results might give the frequency response of a hi-fi system, or summarise interface performance on a set of standard tasks.

Properties affecting the choices in a measurement study

A complete method for a measurement study involves choices at each of the five levels. In the framework we develop here, we discuss the issues that affect the choices that must be made: how to select the best method for a given job. Each level has alternatives, and these vary in several important properties. For instance instruments vary both in how much they cost each user, and in how much they cost the investigator. In addition there are some properties that are affected by several or by all levels. We have organised our material around this idea. The alternatives and properties for each level are summarised together here, but are more fully described in the section dealing with the level with which they are associated.

However there are a number of qualifications that emerge. Firstly the sets of alternatives are all open-ended: there are really an indefinitely large number of them at each level, and here we concentrate on the ones most often useful in HCI. Secondly the choices at different levels are not fully independent, partly (for instance) because some instruments are mainly useful only for some kinds of measure. Thus in practice you only make free choices at some levels, and some others are then heavily constrained. This shows up most perhaps at the fourth level (results), where if you have chosen everywhere else then the method of analysis you choose is often just a matter of reporting everything you meaningfully can given the nature of the data; conversely, if you want to be able to report a comparison (a particular type of result) then this constrains what you may do at other levels (e.g. probably choose an experiment as the instrument, and be careful at the episode level to control all the variables).

Thirdly the testing episode level is somewhat different in that you must make not one but several separate choices (of task, users, machines etc.); however these share some important properties e.g. similarity to "real" practice. Fourthly, the controlled experiment behaves rather differently from the other instruments in terms of this framework because in some ways it is more like a kind of testing episode than an instrument: to do an experiment means on the one hand making choices at the episode level that ensure that the set of measurements are strictly comparable (variables are controlled) and on the other hand other instruments may be employed within it e.g. questionnaires. Nevertheless in practice, an investigator faced with a question such as "how easy

is it to produce a short letter using this word processor" has a choice between (say) doing a questionnaire survey of established users, doing think alouds on a sample, or doing a controlled experiment. Thus pragmatically, if not logically, experiments belong to the set of instruments, and satisfy a definition of instrument as "a means of doing measurement".

Summary of the framework

Measures

Alternatives: time on task, time to learn, number of errors, feeling of enjoyment, ...

Properties:

- Type of unit: Open-ended, events, category, ordinal, ratio scale
  - Comparability: open-ended vs. the rest
- Underlying thing to be measured: User behaviour, knowledge, intention, values, attitudes, ...
  - Internal/external: measure internal (e.g. mental) state or behaviour or "attitudes" (internal estimates of external factors)
  - Measure: machine, environment, or user
- How well are you measuring what you really want to know?
  - (e.g. How close to proposing specific design modifications)

Instrument

Alternatives: Focus group, questionnaire, feature checklist, semi-structured interview, think aloud protocol, incident diary, ethnographic field study, controlled experiment, ...

Properties:

- Whose judgement
  - Comparability: improved by centralised or mechanised judgement
- Internal/external: Measure by asking the user, or by observing what happens
- Cost to user
- Cost to investigator
- Retrospective or on the spot
- Type of additional prompting: none, investigator, other users, ...

Testing episode:

Alternatives: Separate choices of each of:

- Environment (including sources of help)
- Machine
- User:
  - Task (user's current goal)
  - The knowledge (expertise) users have
  - User's permanent characteristics

Properties:

- Comparability: Is the set of instances under each choice uniform (controlled)?
- Validity: Are they natural (representative of the intended set)
  - Laboratory study <—> Field study (Roughly: on this spectrum, the former increases comparability but reduces validity, while the latter has the inverse properties.)
- Coverage of the potential space of bugs

Results:

Alternatives: Transform measures, combine, averages, describe distributions, decide whether two sets are probably distinct (significantly different), ...

Properties:

- Comparability: may the measurements be meaningfully combined, or not?

Report:

Alternatives: Find bugs, compare two designs, compare a design against benchmarks, compare users, ...

Properties:

- Where in the design cycle is the study done (illuminative, formative, summative)
  - (How complete a prototype interface is needed)
- Comparability: does the report's goal require comparison of measurements?

Comparability

There is one important property of measurement that appears at all five levels in different ways — the comparability of the measurements — which we therefore introduce here (since it does not belong simply to one level). Whether comparability is desired is determined by the kind of report that is wanted. If two programs are to be compared, then comparability is necessary, whereas if all that is required is for a list of bugs to be assembled, then it is not (unless data on the frequency and severity of each bug is also required). The importance of comparability emerges at the stage of result calculation: you should only add together things that are comparable (e.g. apples with apples, but not with oranges). If you want to calculate the difference in average time that users of two programs take, this is only meaningful if every other factor is comparable: the task they were attempting, their prior experience with the program and the machine, the speed of the machines' hardware, how much they were told to try to be quick, etc. If the report's goal requires comparisons, then you will need to make some such calculation at the results stage, but it will only be sensible and permissible if comparability has been achieved at the three previous stages. At the testing episode stage, this means setting the same or comparable tasks to comparable users (e.g. all novices) under the same conditions. At the instrument stage, this often means doing an experiment and not a more realistic field study. If you choose an instrument like a questionnaire, then you must think about comparability: will the questions mean the same thing to both groups of users? are the users of each program whom you are asking similar in other ways e.g. age, how busy they are etc.? At the instrument level the property of whose judgement decides the values recorded is also important to comparability: interviews are more comparable than questionnaires because a single person (the interviewer) makes all the judgements; and a measure like time decided by the stopwatch manufacturer is still more comparable. At the level of measures, the issue is that the unit of measurement cannot be open ended, but must be one of the other, comparable, measures (categories, ratio scale, etc.).

Measures (level 1)

We need to make a number of distinctions, which may be summarised as follows. We need to distinguish between the underlying entities that have causal effects (e.g. what a user knows), and the quantities actually measured (e.g. their score on a test), which we hope indicate the underlying entities that we are really interested in. For both of these there are two independent issues: the kind of thing being measured (e.g. time or intention), and the kind of metric used (e.g. quantitative or qualitative). The things measured may be properties of the user or of the machine or environment; and they may be external behaviour or internal (e.g. mental) state.

There are two sense of measure to consider: the underlying things we wish ultimately to measure which in general we believe to be basic causes and effects in the interaction, and the more immediate properties that we measure as evidence of the underlying things. For instance, a simple thermometer measures the length of a column of liquid as a proximal or surface measure indicating the distal or underlying quantity of temperature. A voltmeter may actually measure current, using current through a standard resistance as a measure of voltage. A car's fuel gauge has position of a needle on a dial as the proximal surface measurement indicating the distal quantity of fuel in the tank (the needle depends on the current, the current depends on a variable resistance in the tank, the resistance depends on the height of a float in the tank, and the height of the float depends on the amount of fuel). Thus an instrument is a design for getting an indication of an underlying property, often by means of a measurement of some other, related property. In this section we discuss distal measures: the underlying things we wish ultimately to measure. The proximal, surface measures are the business of the instruments, which we discuss in the next major section.

The kinds of underlying thing to be measured

The first major division of measures is between measures of the machine, of the environment, and of the human user. In principle every kind of measure could be apply to the machine as well as to the user: the overall performance of an interaction can depend on the machine's response time, its errors (if there are bugs in the program), its estimates of a user's abilities (if it has an active user model), its goals or intentions (e.g. programs may have built in "goals" such as saving work periodically without commands from the user). We shall comment on this, but most of what we have to say will concentrate on measures of the user. This is only because most user interface technology so far makes the state and actions of the machine very easy to observe. In particular, the basic feature of direct manipulation is to reflect machine state on the screen, so either a video camera or a human investigator can usually capture the state and behaviour easily. However in future it may be that other interface styles make machine measures more difficult and more important. For instance, if the interface adapts itself significantly, then it may become hard to replicate exact machine behaviour so as to do the same test on different users, and then more attention will have to be paid to measuring and recording exact machine states. (This point is familiar to programmers: many bugs are repeatable,and so are relatively easy to track down. Notoriously difficult are bugs that are intermittent because they depend on some hidden and variable part of the state e.g. network traffic.) In fact as well as measuring the user and the machine, it may

sometimes be important to measure things to do with the environment e.g. the presence and availability of information resources such as the telephone, colleagues at adjacent desks, or a printed manual. The environment is part of the relevant "system" to be observed and measured if it affects the course of the interaction.

The second, independent, major division of types of measures concerns the external/internal distinction: measures that are of external behaviour (e.g. what the user does, how long they take to do it), versus those that are of internal, mental state (e.g. what the user knows, what they were trying to do). (This distinction also applies to observing the machine: external behaviour concerns its output, while internal behaviour concerns its hidden state.) In fact there is a third kind of measure: not only external behaviour and internal state such as intentions, but "attitudes" in the sense of internal estimates of external things. For instance, people generally have rough estimates of how difficult it would be to use a program. These estimates are important because users' decisions about what to try and what to do (and whether to buy a program) are largely governed by these estimates. These attitudes are often approximately accurate even when they do not sound it. For instance, someone may say the don't like a word processor and may apologise for it, but in fact this may correspond to the fact that that word processor takes a long time to learn and the user would not recoup the cost of learning by any benefit for their particular tasks. However whether or not these estimates are accurate reflections of interface performance, they are sometimes important to measure because they independently influence user behaviour. These attitudes, then, are a third class of thing to measure. (They may also occur in machines which have user models: internal estimates (possibly quite wrong) of what a give user knows or wants.)

Examples of attitudes are estimates about how long it takes to do something, about the chances for succeeding at a task, about whether it will be enjoyable. Examples of external behavioural measures are time to complete a task, the number of errors made, what actions a user takes: in particular, which method they choose (the most efficient, or a roundabout one), whether they use shortcuts, etc. Other possible external measures might be facial expressions, or exclamations (e.g. curses).

Internal measures may be roughly divided into three classes, depending on whether they typically vary over a very short time, a medium time, or only over very long periods. Examples of the first class (short time durations) are intentions (what the user is trying to do e.g. to select the command "cut", to delete a letter), and interpretations ("I think that command 'cut' might be for dividing my file into two parts"). Both of these often vary almost from second to second as the interaction proceeds. Examples of the second class (medium time durations) are knowledge of commands, of how useful the machine is turning out to be, of how annoying it feels. Examples of the third class (long time durations) are abilities (e.g. is the user blind?, can they read?), and personality characteristics.

Types of unit (metric)

The other independent important issue for measures is the type of unit in which it is described. This property may be loosely described as qualitative versus quantitative, but more accurately by listing the major alternatives. These are:

- Open-ended. An unstructured answer to a question, or description of the user's behaviour is recorded.
- Event. A definition of an event (e.g. the user opens a menu but then closes it without selecting a command) is used, and everything that happens is classified as either an instance of the event or not.
- Categories. Whereas with events, most things are not recorded at all, here most things are classified into one of a set of categories. For instance user behaviour might be classified into: typing, using the mouse, gazing at the screen, thinking. However there is no particular way to rank the alternatives.
- Ordinal measures. Here the categories used have a definite order. For instance users might be asked to score each command as "difficult", "moderate" or "easy"; or their use of each command as "very frequent", "frequent", "seldom", "rare", "very rare". These categories have a definite order, but probably no further reliable numerical properties: for instance, is "seldom" twice as frequent as "very rare"? Many questionnaire questions use numbers as response categories, but you shouldn't therefore believe that it is sensible to add or multiply them: unless you have direct evidence that this makes sense, you should treat the numbers as expressing only order. (This is just like the use of numbers in programming to represent different cases e.g. 1 for red, 2 for blue, 3 for green. Numbers are convenient code labels, but arithmetic cannot be sensibly applied to arbitrary codes.)
- Ratio scales. Some units however *are* part of scales (e.g. time), and it then makes sense to apply arithmetic.

The major division in the above spectrum of types of metric is between open-ended and the rest. The rest all support some kind of quantitative comparison between subjects or measures, while the open-ended does not. On the other hand, only the open-ended can allow the investigator to discover something wholly unexpected such as a bug. Qualitative, descriptive methods are important for getting impressions about what is going on between the user and the interface — in a sense they are the bedrock. Without the intuitions gained from them,

quantitative methods make no real sense. Thus for comparability, quantitative metrics must be used, but to discover the unexpected (as opposed to testing hypotheses, or measuring standard features) some open-ended measure must be used. The choice then often depends on the goal of the investigation (the report type), but it is also common to see the types mixed, or to have an investigation in which the first phase uses open-ended measures to get an overall picture, and a second phase uses quantitative measures to give a detailed picture of the issues identified by the first phase.

It is also possible to record open-ended data, and then to categorise them by some coding scheme at a later stage (of result calculation). This has the advantage of allowing several different analyses to be done later, but the disadvantages that it is often an excuse to defer until later the vital decisions about what will be done with the data (which often affect how the measures are taken), and that it prevents the investigator getting the subject to help with the categorisation ("which did you really mean?").

Further examples

In principle we can fit everything we might want to measure into the above scheme. For instance we frequently wish to measure users' "past experience". This is an external measure (for how long they have actually, in the past, used a give program), which has a ratio scale (e.g. hours). To measure the past, of course, necessarily requires indirect measures. Whether we ask the users themselves, or consult records of their past activities, is a matter for the instrument we select. Past experience is a question of external behaviour, but in fact very often what is really wanted is a measure of what the user now knows (their expertise) which is an internal matter of knowledge: it may be better to measure that more directly, either by asking what they know or by testing their ability behaviourally (which would constitute an external type of instrument seeking to measure internal knowledge indirectly). Knowledge does not really have an applicable ratio scale despite the practice of examinations: if user A scores twice as much as user B on a typical test, they may know everything B knows plus some more, or they may know a different set of things.

Another case is value judgements. How much a user values the benefit of employing a program (its utility) is a medium term internal measure, while how much a user enjoys or dislikes using the program is a different medium term internal measure (part of its usability): some programs are not used because although quite usable they aren't useful, while others are used although hated because they do something vital. One common measure is questions with answers on an ordinal scale (see the section on questionnaires). Although these things are internal, another way to measure them is through an instrument looking at external (behavioural) signs: we could record facial expressions, or offer people a choice of programs with varying utility and usability and use their choices as indicators of the values they put on them.

An issue of importance for designers is what commands are needed by users. This could be inferred from what commands are used frequently (i.e. use an instrument whose surface measure is command use). Users could be asked during use whether they needed that command as opposed to it being an accidental invocation: this would be a direct internal measure. Users could be asked retropsectively about what commands they needed, which would rely on their memory: an internal surface measure directed at an internal underlying issue. Need is either a binary or an ordinal scale (for degree of need) applied to each command separately.

A final case is that of errors. These are frequently used as an external measure, but this can be problematic because it is not always clear what should count as an error. The essential trouble is, that our intuitive notion of error is really an internal one: doing something which we would not do if given a choice. But this is seldom what is measured. Instead "errors" are usually defined as an external measure: a particular class of action. However, is it an error to do something unnecessary? Users would probably agree that deleting a file by accident is an error. But looking up something in the online help is also unnecessary (if you had learned it before). Similarly, typing at a reasonable rate involves inserting some wrong characters, but if the alternative is typing extremely slowly then perhaps this should not be regarded as an error. Not convinced? Well what about opening a pulldown menu, moving the cursor very fast to the approximate position, pausing, then correcting the position of the cursor until it is on the command you want: was that an error? It cost you time, and obviously you would prefer it in an ideal world if your cursor had landed on the right command first time. In the end how a measure is defined may not be a general objective issue, but may depend on the purpose of the whole measurement study: the five levels are not wholly independent.

In fact nothing we have said so far tells you what measures will be useful: the scheme we have just described is only a way of organising the space of possible alternatives. How useful a measure is depends on how well it matches the overall purpose of the measurement study (the report type). This degree of match is an independent property of a measure in relation to a particular study. A useful definition of error depends on your aims, though in any case it would be sensible to ask a few users what *they* feel counts as an error in the situation you are studying. Another case is that of bug descriptions. What is ultimately wanted by designers is

descriptions of feasible modifications (e.g. "the command name should be changed"), although it may be hard to do better than descriptions of symptoms ("several users got lost while attempting to move text"). Either of these might be categories or events or open ended descriptions; it is a separate issue whether the investigator is able to get evidence not just of the existence of a problem, but of its cause and hence approach possible modifications.

Summary of properties of measures

Type of unit: {Open-ended, events, category, ordinal, ratio scale}
    Comparability: open-ended vs. the rest
Underlying thing to be measured: behaviour, knowledge, intention, attitudes, ...
    Internal/external: measure internal (e.g. mental) state or behaviour or "attitudes" (internal estimates of external factors)
    Measure: machine, environment, or user
How well are you measuring what you really want to know?

Instruments (level 2)

Above we discussed measures, and their alternative properties. In principle any instrument could be used to take any measure, but in practice some make much better sense than others, and we will note these main applications as each instrument is discussed. For instance one could use a questionnaire to ask users about anything, but in practice people remember some things much better than others, so they are much more useful in asking about stable habits and attitudes, than about what someone was thinking about on a particular occasion.

Instruments, then, are ways of doing measurement that have largely evolved to achieve some particular point in the space of alternatives already outlined, and also in the space we outline below as determined by properties of instruments themselves. They are not in practice fully independent of the other levels, and this is noted in the sections discussing each instrument. In particular, as noted earlier, the experiment has many of the features of a testing episode as well as of an instrument. However in this framework we discuss them as if they were independent so that you can see what the logical alternatives are, even if some of them have little application.

We now discuss some properties specific to the level of instruments, before describing seven alternative instruments.

Internal or external surface measure

The underlying thing being measured may be internal (e.g. mental state) or external (e.g. behaviour), but independently of that, the surface indication used to measure it may be either internal or external. Thus instruments may be divided into whether they are internal — ways of asking the user — or external — basically to do with observing and recording user behaviour. This choice is in principle independent of the choice of underlying measure (though some combinations work better than others). For instance you can ask a user about anything: about external matters of behaviour (how often have you used this command), or internal ones (what are you trying to do now). Conversely, besides using external methods for external measures (e.g. use a camera to record keystrokes), you can try to estimate internal matters from external ones: use facial expression to indicate feelings, use the length of a voluntary rest to estimate how tiring the user found the previous task.

How the measure is made? (whose judgement)

Whose judgement or interpretation determines the recorded result or measure that is aimed at inferring an underlying entity? There are basically three possibilities:
    A device e.g. a stopwatch, store keystrokes in a file
    An observer e.g. the investigator perceives a gesture, judges an intention
    Each subject (user), when asked to reply to a question

Note that although at first the method seems to be determined by what is being measured (e.g. if it is time then use a stopwatch, if an intention then ask the user), in fact there is a large overlap of possible methods. For instance, a user's past experience with computers is an objective fact which might be measured without intervening human judgement, but in practice it's easiest to ask the user. Similarly you can ask someone what they are trying to do, or an observer may judge it (as when you see the cat with a paw in the goldfish bowl and infer that its intention is not to cool its feet), or even estimate it mechanically as burglar alarms do.

Devices have the judgemental criteria built in (e.g. electrical meters or gas chromatographs) as the result of a history of research and debate in the literature. If observers are classifying behaviour, then you need to train them and provide operational definitions of each category used, in a way comparable to devices.

Devising explicit judgement procedures. One way round the problems of getting observers or subjects to make reliable judgements is to make the judgement process more overt and mechanical. For instance we might decide to judge whether a user is a novice or expert by setting them a test, and defining an expert as one who scores more than 50%. Strictly speaking, having a device (e.g. a stopwatch) make judgements still involves human judgement in two ways: someone still has to read the watch, and the issue of defining time in terms of what a particular watch measures involved both theory and judgement. However the gain is large: watches are easier to read than being trained to judge time intervals oneself, and they make far more repeatable measurements. The debates about timing were done once and for all, and nowadays are effectively frozen into instruments like watches and do not call for further discussion.

Because such meters for aspects of human thought and behaviour are much less established, we are often involved in developing them for specific purposes. Thus instead of asking people whether they were expert, we might devise a standard test. In fact many measures involve something like this. For instance you might want to know how often people use a command, and use a monitoring system built into the interface to record this. The problem is, some uses will be accidental (perhaps through typing errors, or the mouse slipping while doing a menu selection), so you are not getting the measure you really want. In general, observing people's physical actions is not a wholly reliable clue to their "actions" in the everyday sense, which also involve their intentions.

Asking people a lot of questions about details, and putting together the final category judgement oneself, preferably by a fixed explicit algorithm, is a way around this kind of problem. The essential idea, like building stopwatches, is to reduce the amount of complex case by case judgement in favour of using a uniform method for every case. Thus using a trained observer can be made more like a device, and more reliable than asking each user to make a judgement separately.

There are two basic ways of collecting measures of verbal output from the user. Either one must provide the user with some way of making a response in a directly categorised or quantitative way, such as a set of response categories or a number; or allow a response in natural language, so that the investigator can categorise it. The first is usually done by giving the user boxes to tick, or asking for quantitative estimates in terms of numbers. In the second, the investigator must develop a way of categorising different kinds of verbal reply.

This is the essential difference between questionnaire and interview types of instrument, and the issue of what the interviewer is prepared to do in the way of interactive probing. In both cases the goal of the investigator is to be able to categorise the user's response and then to count these categorised responses. Typically then, responses of a range of users in each category can be tabulated, and calculations made to infer underlying entities shared by a population of users.

The issue is first that English is a vague language, and you may need to chat quite a bit before the user understands what you are after. Secondly the user may not have, as mental concepts, the categories that your theory is requiring you to use. In other words you will have to teach them new concepts; or else ask them a set of diagnostic questions in order to decide yourself what category they or their experience fit into.

Another alternative is to let the user speak or write in unprompted English. But then the understanding burden is on the investigator and again being able to discuss what was meant with the subject is usually invaluable. In summary, either the investigator or the user can choose the language (e.g. in questionnaires or open-ended comments respectively). However two-way dialogues are much better than either alone.

Issues in asking

If you ask the subject/user, then there are two parts to this issue. One aspect is the factors influencing their judgement, basically influencing the access they will have at the time of the question to their own consciousness and memories. The other aspect is the communication of the meaning of the question and answer categories from questioner to subject. Questions should of course be tested to reduce ambiguity and lack of clarity. They may then be aided by prompting: the kind of prompting used varies depending on the instrument.

Prompting

Prompting is important for two reasons: clarifying the question, and helping the user to remember. The alternative kinds of prompt include:

No prompt (questionnaires)
Verbal prompting (semi-structured interviews with probes)
Reading
Behaviour i.e. subject does things (if an instrument is administered during interaction e.g. diaries)
Videotape (record a subject and ask them to think aloud later, while watching themselves on videotape)
Other users (as in a focus group).

Memory issues: do they know the answer?

Asking the user is the "internal" method: one of the two general approaches to measurement. We have just discussed how to get the most out of questions and answers, but even more fundamental is the issue of whether the user knows the answer even if you ask the question in the best way. The first issue is that of accessibility to consciousness: is the underlying thing to be measured something we know about anyway? For instance we are not aware of many of the muscle movements we make, nor of how we recognise things. A second issue is that we may know some things yet be unable to recall the answer except in the right circumstances. It is well known for instance that recognition of something is usually much easier than recalling it in answer to a blank question. For instance few people can write down all the commands on the menus of a program they use regularly, yet if given a checklist of the commands, they can recognise them and say whether they use them often.

The third issue is simply that some things are transient: forgotten very quickly. You are unlikely to be able to remember the mouse movements you made at your computer yesterday; yet if you had been asked at the time, you would have been able to say what each one was for.

Retrospective vs. on the spot

One of the most important properties of an instrument is whether it is retrospective, or on the spot. I.e. whether subjects have to rely on their memory, or whether the measures are applied to events at the time. As we have seen, there is an important class of things which are accessible to consciousness, but which we forget very quickly: these are are the things which it is important to have an on the spot instrument to pick up. These things are internal measures with a short typical time span; for instance, intentions, and interpretations of what a display means.

Costs

An important property of an instrument is how much it costs to apply, and they differ greatly from each other on this issue, which is of considerable practical importance. In fact there are 2 kinds of cost (in time and money) of applying the instrument:

Cost to the subject (user) e.g. time to fill in a questionnaire
Cost to the investigator e.g. time to design an interview
and the time to carry out the interview with each subject.

Summary of properties of instruments

Whose judgement? {user, investigator, instrument}
Measured via a surface measure that is {internal (ask the user), or external (observe the user)}
Cost to investigator
Cost to each user
Retrospective or on the spot
Prompt type
Typical measure
Typical testing episode
Typical result calculation
Typical report goal

Instrument 1: Focus groups

Primary function
The distinctive feature of a focus group is that it is a group setting, where users talk in free-form discussion with each other more than with the investigator, whom they outnumber. It maximises the chance of hearing not just what users think, but the way they think: it aims to elicit associations and connections that *are* in fact important to the users, but tend to get missed by other methods because they are not obviously functional and businesslike. Thus focus groups are intended to discover what might otherwise be missed because it is unsuspected. Focus groups can be used in three ways.

The first is very early in the design, to broaden the requirements for a design, by discovering what goals and associations actual users have in this area. It is a supplement to task analysis: a formal analysis of what tasks users actually or officially perform. In a focus group, you can discover how they actually use the existing system and what concerns are actually important for the users. It is thus an important alternative or supplement to task analysis and the project requirements drawn up by managers. You can use focus groups in this way for studying a) existing user wants and tasks b) associated user thoughts and especially emotional connotations — what they want, and why they will be performing those tasks c) How they think about those tasks, which will have implications for how they should be asked to express parameters to the system e.g. are they moving windows to fixed coordinate positions, or to "look right" d) prior user experience (concepts of how-to). This can be and should be done before any design or implementation, to provide basic data for the design.

The second application of focus groups is as a debriefing session, as an alternative follow-up after exposing users to an interface rather than (or as well as) interviews and questionnaires. A particular advantage here, is that it may be possible to tell subjects that they have "failed" with much less hurt to them, supported by their peers who are either in the same situation or in any case have no particular respect for the device. And one user's remarks may prompt another into mentioning something which would otherwise be lost.

A third application is as an alternative to questionnaires for measuring users' affective and other attitudes. Whereas questionnaires are often structured, or else ask open ended questions with limited ability to put the user in the right frame of mind, focus groups encourage and support extended expressions of judgements and feelings. It can allow investigators to see vividly how users bring non-computer experiences with them: for better or for worse. Designers who are unaware of this will never understand why customers are avoiding their work.

Basic idea
Get together an audio recorder, 4-6 users, and an investigator to lead the discussion. Introduce a list of pre-set topics one at a time, and facilitate free discussion. A session might last, say, 45 minutes. The main aim is to find out how people naturally think about the topics, so the method makes sure that users outnumber the investigator (unlike any other method), and relies on chance remarks by one person to trigger others.

Method
Prepare the questions or topics (the "focus" of the group). Use an audio recorder, and bring together 4-6 users, and an investigator to lead the discussion. Introduce the list of pre-set topics) one at a time, facilitate free discussion including ensuring that everyone is heard, ensure that clarification of all (!) vocabulary and concepts used is made. The designer may wish to be present, or to listen to a recording later.

If it is pre-design, then the chief aim is to elicit the natural habitat of the proposed device, or at least of existing members of its species: how it is used. This breaks down into several distinct questions:

- What the associated aims and feelings are. E.g. heating controls seem to be used by one person on behalf of a whole household, so the goals are not personal, and are taken seriously (?like first aid kits and not like VCRs). This is vital in that it is a measure of the value attached by users to the function performed: the denominator of the all subsequent tradeoffs of cost.

- What are the tasks and their exact mental specifications that users perform with the device. E.g. do people think of putting the heating on for 2 hours, or from 6:20 to 8:20, or from 18:20 to 20:20? Do they want it on "over lunchtime" or "from 12 to 2". Do they come in and want to be able to turn it on in one button push, and then forget it? Do they really think of "I want it warm by 6:30" or "I want it to start warming at 5"?

- What are the devices and associated methods and habits (of both thought and action) that the users currently employ? This will affect what interface methods they recognise readily.

If it is a post-trial debrief, begin with refreshing their memories with a demonstration and telling them how it really worked. Ask them what they feel about the device, whether they would use it etc. Try out probes on the investigator's hypotheses about the sources of trouble observed. Get them to propose modifications (e.g. on paper) as another method of eliciting what they really think was wrong, and what the device should really aim at doing.

Analysis

There are two ways. A qualitative analysis notes the concepts that emerge, and evaluates their implications for the purpose. Usually less relevant, a quantitative analysis would count or collect instances of particular concepts. To be meaningful, this would require that the group leader to elicit comparable amounts of comment from each participant.

Bibliography

D.L.Morgan Focus groups as qualitative research (1988) (Sage: London) [SocSci A370 MOR2]
T.J. Gage "Theories differ on use of focus group" Advertising age vol.4 (1980) 19-22.
R.Foshay Guidelines for evaluating PLATO programs TRO technical paper no.2 (1992) p.23; available at: http://it.coe.uga.edu/itforum/paper50/paper50.pdf

Summary of properties

Whose judgement decides the data: It is conducted in the users' terms; not dependent on their understanding of investigators' concepts. And can be used to discover users' concepts and the words they use for them. Thus: data is in user terms and not distorted before recording. This leaves the problem of translating it into investigators' terms (something to try to ensure in the group), and of comparing different groups.

Internal / external surface measure: Internal — ask the user

Cost to each subject: the time for the session (say an hour).

Cost to the investigator: Preparation time. 1 hour running each group, plus time to organise getting the subjects there. Money for the subjects' time. Analysis time.

Retrospective or on-the-spot?: Retrospective. (Hence not good at capturing behaviour; but good for measuring attitudes, affective stuff, persistent concepts, user vocabulary for concepts.)

Prompt type: Other users' comments, investigator's general questions.

Typical measure Tasks and supertasks. Bugs mentioned.

Typical testing episode Can't easily compare it to other groups in that the discussion will develop differently in different groups, and may depend on what gets raised by the subjects. However the topics raised are the same, and it would be possible to apply a uniform coding scheme. Ecological validity entirely depends on the discussion. It can be used to elicit information on real situations of use.

Typical result calculation Count tasks or bugs mentioned.

Typical report goals Pre-design requirements capture; debriefing for bug detection.

Other remarks

It is the only one of these instruments to use peer interaction and groups. The advantages of this are that the discussion will be more natural than with the investigators, and that subjects may prompt each other more effectively than happens in semi-structured interviews. The effect is probably something like: when a single subject talks to an investigator, they select their utterances to fit in with formal ideas about skill, objective aspects of the interface, being business like. When talking to peers, subjects select what they say for being recognisable (understandable) by their peers: so common situations, feelings, anecdotes come out. We need this because subjects' ideas of what is formally relevant are probably not a good guide to real relevance, and because whether and how people choose to use devices in real life is probably influenced by things other than "formal" factors.

Listening to others talking may be valuable not just for setting a different tone than the investigator easily can, and not just because one user's remarks may act as a prompt or probe and trigger another user; but also just because it takes time without boredom and yet staying on one subject for memories and associations to surface — groups talking can do this.

Example of prompt sheet for leader of a focus group

Focus group on personal organizers : points to cover

- Usage now of diary, alarm, address book, notebook, etc. including where carried and how often used.
- Problems with the current means of doing these functions
- Extras that could be included by a computer based device
- What one would ideally prefer such a device to be like
- What are the snags?

Instrument 2. Think-aloud protocol

Primary function

The main function of this method is to allow rapid and immediate qualitative feedback from the user about what it is like to use the interface. It is the closest one can get to a window into the mind of the user. It is related to simply observing user behaviour (without asking them to think aloud). If the investigator has particular issues in mind, they may ask specific probe questions in which case the method becomes similar to a semi-structured interview conducted withthe task at hand. Incident diaries may be used as an alternative, to investigate infrequent events.

Basic idea

This method involves asking colleagues, friends, and then, more especially, people from the potential user population to use the interface. While doing so, the user says whatever comes into their mind.

Method

Sit with the user so that you can see the interface and the user's actions.

Introduction. Say that the interface, system etc. is being developed, or evaluated, and it would be of great help if the user could use it, and while doing so to say what s/he is aiming to do, where s/he gets stuck, what problems arise — in fact everything that comes to mind when using the interface. Say that you want mainly to listen, rather than to give advice at this stage, because it is important that the interface can be used by people without an advisor present.

Think aloud protocols consist of observing a user interact with a system while encouraging them to think aloud: to say what they are thinking and wondering at each moment. They are a simple extension of the most basic method of observation: just watching users. You can see a lot by just watching, but when users hesitate you cannot often tell why, so having them tell you is very informative. Similarly when they commit what you see as an error, you need to know why, and they can tell you.

Although you can tell what people are doing and why while they are performing as you would, when they do something unexpected only they can tell you what their intention is; when they are puzzled, usually only they can tell you what the puzzle is; when they choose the wrong menu item, only they can tell you why it seemed the most likely to them.

People can in practice only tell you about what they are thinking for thoughts that take an appreciable time — such as puzzling about something. They cannot tell you about very fast mental processes — e.g. touch typists cannot say anything very useful about how they decide which fingers to move, or why they sometimes make errors. But people can with a little encouragement talk about some of the things most important to designers: what seems obvious or obscure on the screen, what users want to do at a particular point, and so on. The advantage of having them talk aloud as they act, is that people quickly forget almost all the details of little puzzles and errors, so asking them afterwards in questionnaires or interviews will miss all except the most painful experiences. In fact in many cases, a new user does not know they are making an error at the time, even though this may be painfully obvious to an observer, so live observation gathers more, and more valuable, data. Think-aloud protocols can be done on any kind of user at any time. However they are most often done on new users, because problems typically come very frequently then, so that it is worth the observation time. Also, as users become more experienced they understand more of what is happening, and are more likely to be able to make a detailed report later.

To gather a think-aloud protocol, the basics are a willing subject, sitting down at the system and a pad to take notes. Then let them begin. Recording sound or video has the advantage of allowing you to go over the tape later to observe more details, to get the subject to discuss it with you. The biggest advantage however may well be in communicating with the designers: a video tape of users having problems is convincing as nothing else is when arguing for changes to a system.

You need to get the subject at ease in talking aloud. The first thing to do is to make it clear that it is the system not the user who is being tested and criticised. Say that your aim is to build a system that will let anyone have a trouble free time, and you want to hear about even momentary puzzles and problems. The second thing is to apologise in advance for being there in a chatty situation but refusing (as you should) to give them any useful help even when they ask for it. This is unnatural, but (as you should tell the subject) you need to see whether they find an answer to their difficulties themselves, or whether the problem turns out to be a big one.

This is not a rigid rule: it is just that the more you help subjects by answering their questions or giving them hints, the less you find out about how the system performs for users without an adviser sitting there. It is hard

to resist your normal impulse to be helpful, but mostly you should. However if they get totally stuck, you may decide that you will learn more from the session by giving them a hint so they can get going again (make a note of the hint, which obviously the interface should have provided itself). Again, if you have already decided to change the system to provide some bit of information, you might decide to give it verbally to the user in order to simulate what the system will be like.

As the session proceeds, you should feel free to prompt them to do more thinking aloud, and to ask specific questions e.g. they look puzzled and pause, and you might ask what they are wondering about, and what it is they want to find a way to do. There is nothing wrong with you saying quite a bit — this helps to develop a chatty and informal atmosphere — you just have to do it in a way where the subject talks about their thoughts and opinions, but you do not mention your opinions or knowledge of the interface. You should however show your very real interest in their thoughts.

Think-aloud protocols are open ended and non-directive — they are mostly for finding bugs, not answering predetermined questions. As open-ended measures, they are better than interviews because they probe during not after the event. They are about recording problems (symptoms), not how to change the design: thus they need later interpretation by designers. Thus interviews might be used to ask about problems encountered when the subject was not observed; we needn't ask about problems during observation. We can ask the subject's views on what to change, although this is unlikely to be useful except as another way to indicate areas that have a problem, or to tell about new functions needed (only users can tell about goals).

Recording. Your main task will be to jot down what happens. This may be helped by a structured data sheet. We will provide one that has some categories to observe, and that can be used as prompts. Note taking is important even if you are tape-recording the session. Minimally an investigator sits beside her at the interface, making notes. More elaborately the sessions can be video or audio recorded for later analysis, and keyboard strokes can also be recorded. The more elaborate methods are not typically necessary however, in most applications. Rather the interface should be offered to several users until basic problems are discovered.

Prompts. Particularly if the user stops talking, ask: "What are you thinking now?", "What are you trying to do there?", "Why did you do that?" and so on.

Hints. The method is entirely informal, with no fixed procedures. It depends largely on your skill in creating an informal atmosphere, free of any suggestion that the user is being tested, or evaluated.

Analysis. The analysis of these protocols is in terms of the content of the commentary of specific episodes of action by the user, so-called content analysis. Content analysis means assigning naturally occurring utterances to categories. E.g, for each episode: Is it obvious to the user what goals s/he might have with the system? How does s/he form a plan to achieve each goal? When implementing a plan, is what happens expected? How does the user recover from unexpected events?

All this can, however, be done informally, assisted by note-taking data sheets laid out with headings. Quantitative content analysis is usually best done from recordings.

Variations

Question-answering protocols. This alternative has been used with subjects who are shy, or who might otherwise be reluctant to speak their thoughts aloud. Here the user asks the interviewer how to do this, that or the other. The interviewer thereby gains a sense of what is obvious from the interface and what is not. The disadvantage of this is that the essentially passive role of the user, and the direction by the interviewer, prevents some some of the bugs that a lone user will discover from being encountered.

Constructive interaction protocols. These require two people to work out together how to use the interface, with the interviewer listening in. Again, the conversation that emerges will be informative about the features of the interface that are misleading or unhelpful.

Do it yourself evaluation. This method is important when you want to evaluate a product for yourself, rather than primarily to consult or observe other users. It is usually important to have a set of features, goals, guidelines etc. to watch out for.

Logging speed, errors, and other performance measures. It is hard to make any useful evaluation without using either think aloud protocols or semi-structured interviews. In either case, the psychological measurements can often be enhanced if they are accompanied by performance measures of various kinds, for instance from logging keystrokes of a session, or video recording the screen.But whereas think-aloud protocols are helpful on

their own, logging or recording sessions is not very much help without some data about the user's goals, plans, thoughts etc.
Behaviour Observation. Watch (either via video or live) the activity of users, but without interacting with them or requiring them to talk aloud. What they do can be categorised and counted.

Analysis
A list of symptoms, plus your interpretations of these especially as you begin to see similarities between users's problems.

Bibliography
R.L.Mack, C.H.Lewis, & J.M.Carroll "Learning to use a word processor: problems and prospects" in either: R.M. Baecker & W.Buxton (1987) "Readings in human computer interaction: a multi-disciplinary approach" or in: ACM transactions on office information systems vol.1 no.3 (1983) pp.254-271

J.M.Carroll & R.L.Mack "Learning to use a word processor: by doing, by thinking and by knowing" and in: Thomas & Shneider Human factors in computer systems (Norwood NJ: Ablex) (1984) pp.13-51.

Method
Ericsson, K.A. & Simon, H.A. (1980) Verbal reports as data *Psychological Review* vol.87 215-251.
Nisbett, R. & Wilson, T. (1977) Telling more than we can know: verbal reports on mental processes *Psychological Review* vol.84 227-236.
Gilhooly,K. & Green,C. (1996) “Protocol analysis” chs.4-5 pp.43-74 in Handbook of qualitative research methods for psychology and the social sciences (ed.) J.T.E.Richardson (BPS books: Leicester).

Summary of properties

Whose judgement? investigator, or behavioural measures too.
Internal / external surface measure: Both — ask the user and observe the user
Cost to investigator The same, repeated for each subject. Expensive.
Cost to each user The length of the sessions: 10 min to hours
Retrospective or on the spot On the spot.
Prompt type: Investigator; and events with the machine.

Typical measure Bug descriptions (open ended). Both behaviour and intention.
Typical testing episode Just apply this instrument. May set specific tasks, or not. Both Field study and lab. study, but never very controlled since the task is at best weakly specified, and the probes and reminders to think aloud will vary widely with different subjects.
Typical result calculation Count frequency and cost of bugs.
Typical report goal Debugging an interface

Instrument 3. Incident diary

Primary function
The main function of this method is to provide the user with a simple means of recording examples of events of interest to the investigator, but without the necessity for an interviewer to be present. It is thus an alternative to think aloud protocols, which can be used for acquiring information about relatively low frequency events that might occur after the main, high-frequency bugs have been eliminated.

Basic idea
The basic idea, at the abstract level, is to have an instrument that is an on the spot questionnaire (not a retrospective one). Thus it is mainly targeted at measures that are of transient and forgettable, rather than stable, items; events, thoughts, and emotional reactions, rather than attitudes and degrees of familiarity. It is always a recorder of events, and may or may not additionally record some of the attributes of those events. Thus there is a range of functions for it: from just event (frequency) recorders, to complicated open ended descriptions of the events (recorded as soon as possible afterwards). Two fairly extreme examples: 1) a pilot writing an accident report (high motivation, lots of detail, rare event) 2) A user recording how often they do some action, and perhaps why they did it: an alternative to a checklist. User motivation and memory for doing it is the key problem, and depends on the combination of frequency, the cost of filling in each entry, and the importance of the diary to the user.

The basic idea of this method is to provide the user with structured forms on which s/he can record what happens when certain kinds of event occur. One such event of fundamental importance to the designer or the documentation writer is the user getting stuck. The example diary which you will administer in this course is about what happens at these points.

Method
The investigator has two main problems.

A. Designing the diary. The following steps will give a guide

i. Define what events you want the user to pay attention to
ii. Give at least one example
iii. Lay out the diary in an easy to read manner, so that s/he can fill it in with a minimum of thought, and taking a minimum of time. (Giving the users too much to do will mean that they will not fill the diary in at all! Users are reluctant to interrupt their ongoing plans.)
iv. Ask the user to estimate how accurate s/he has been in completing the diary

B. Getting the user to fill in the diary. The investigator often has to be careful to ensure that the user knows what events s/he is being asked to record. This may require some training, and is often best done by prompting the user during the first few episodes if this is at all possible.

Advantages
The important advantages with a diary are that once the user has taken on the task of completing it, information can be collected very cheaply, and without further investigator intervention. One kind of diary that is very helpful, for instance, asks users to record what they do when they get stuck for any reason, or have to consult a source of help.

However, although diaries may ask open ended questions, they are usually only useful with focussed questions. Thus it is rather a controlled measure, good only for pursuing relatively specific questions.

Variation
A variation of asking users to record a specific kind of event, like getting stuck, is to ask users to give structured reports on new interfaces. Many companies have a small group of customers who will provide them with feedback in this way, before a product is released more generally. Other even less formal versions of this involve having complaints departments, logging user phone queries and so on. Though such methods can all be helpful, two cautions need to be observed:

i. data collected in these ways, from special or self-selected groups of users, may be unrepresentative of users in general
ii. though complaints, phone queries, etc. can generate very specific suggestions, it is seldom the case that users will know what to do about the problem — in other words these suggestions need to be treated as species of measurement, not as things to control a design or decision process.

Analysis
Depends on the measures used. For events and times, simple numerical summaries. For a diary on the sources of help, compile a comparative table showing comparative use. For open-ended questions, as for think-alouds you will report the symptoms plus your interpretations.

Bibliography
J.T. Reason & K. Mycielska (1982) Absent minded? The psychology of mental lapses and everyday errors (Prentice-Hall: Englewood Cliffs, New Jersey).

Summary of properties

Whose judgement? Subject's, but after training for non-behavioural data.
Internal / external surface measure: Internal — ask the user
Cost to investigator Small: but if training is needed, may have to attend for a while.
Cost to each user Only 5-60 seconds per entry.
Retrospective or on the spot On the spot if the subjects remember (but in practice often filled in some time later).
Prompt type: The diary, events.
Typical measure Event counts, category questions
Typical testing episode Long time periods, just this instrument applied alone, no set tasks: field study conditions.
Typical result calculation Frequency counts.
Typical report goal Debugging an interface

Problem: Getting subjects to remember to fill it in.
Advantage: Capturing observations in rare and hard to get at situations.

Example: Diary of getting stuck
[Front sheet]

Surname **Date**
Forename

Please fill in a page of the diary whenever a Problem occurs

Definition of a "Problem". Whenever you have to break off what you are doing to consult one of the following sources of help, we will call this a "Problem".

Sources of Help:
Sought on-screen Help
Consulted manual
Asked other user
Consulted notes
Watched other user
Asked advisor
Other source of Help

Please record the first five problems that you encounter, by filling in a separate page for each.

After that, please answer these questions:

Did you remember to fill in a sheet for every problem? For what % of problems did you forget?

Did you remember to fill in the sheet at the time the problem occurred, or later? How long after the problem on average?

<Then on separate pages, come copies of the diary form:>
[Incident sheet]

1. At what time did the problem occur .....

2. How was the problem triggered? (Please tick one.)

Unhelpful screen message
Other unexpected event
Need to know something to carry on
Curiosity
Other

3. Which of the following Help facilities did you try first? (Please tick one, and say how long it was until you got the information, including the time spent using the resource.)

On-screen help, including menus	Minutes till help obtained? .....
Manual	Minutes till help obtained? .....
Asked other user	Minutes till help obtained? .....
Watched other user	Minutes till help obtained? .....
Asked Duty Advisor	Minutes till help obtained? .....
Other	Minutes till help obtained? .....

4. Did the information you got resolve your problem? (Please tick one.)

Yes, completely Yes, partly No

5. Which of the following statements best describes how much you knew before you started to try and solve your problem? (Please tick one.)

Had no idea where to start looking for a solution
Knew in general where to start looking, e.g. a chapter in the manual
Knew facility existed but not its name
Knew name of facility but not how to use it
Knew how to call facility but not how to tell if it worked correctly
Other (Please specify) .....

Instrument 4. Feature checklist

Primary function

The main function of this method is to discover which features are actually used by users. A great deal of effort goes into the construction of new features. Little effort as yet goes into determining which are used and by whom. Some features simply serve to make the system more cumbersome, and this can have a substantial effect in putting off people who are attempting to learn the system. More generally, we can use feature checklists to help find out why features are unused: e.g. because a command is unknown, because it is unnecessary, because it does not perform the functions the user needs, etc. So we want to ask about usage, knowledge, need, and sources of information.

The main alternative instrument is automatic logging by the system of command usage. If this is available it should be used in combination. Logging does not rely on users' memories; but it records only usage, not need or knowledge i.e. you cannot conclude that a user does not know a command because you do not observe their using it during some period. Logging also records accidental uses (e.g. typing slips) which are potentially misleading.

Basic idea

The idea is to have a checklist of all the features of a system, and response categories indicating usage, knowledge, need, and sources of information. If there are short cuts e.g. keyboard command equivalents on the Macintosh, ask about knowledge of these as well for each command.

Checklists are simple lists asking what a subject knows about something e.g. a list of all the commands in a system. Since all the subject has to do for each item is to check a box, they are very quick to fill in even if they contain many items. They are an example of measuring what subjects know or do by relying on their own memory and view of themselves. This is normally accurate for remembering whether they know a command and how frequently they use it. It is unlikely to be accurate for whether they have ever executed a command accidentally or as an experiment while searching for some other function.

The most common application is to detect commands that are seldom or never used. When such commands are found, designers need to know whether the command is not in fact useful to users, or whether the interface (including documentation) has failed to alert users to its presence, or to allow them to discover how to use it.

Thus we want to discover whether a command is useful, whether it is known by name, or at least known of. (Frequent) use of a command implies all three, but lack of use requires more detailed questioning. To address this, an elaborate checklist might contain one line for every command or feature of a system; and for each, ask whether the user suspects the command's existence, knows how to execute it, thinks it would be useful, has ever used it, and how frequently.

Method

Design and pilot the checklist, and distribute it, preferably to people who have used the system for some time. New users may not know the names of various features, and their usage will not have settled into a pattern.

Usage: The main issue to pay attention to is to ask people to give specific quantitative estimates. E.g. "How many times did you perform a **Save** each hour during the last day when you were were word processing?" Not: "Do you save, infrequently, sometimes, often...". Remember that user's memories are fallible, so try not to leave too long between performance and filling in a checklist.

Check for knowledge: For each command — ask if user: suspects/expects that such a command exists, if they know it exists, if they have ever used it. An issue here is whether to describe the function or name the command or both.

Check for need: You can ask whether they ever need this function, and current frequency of need, and their view of how this corresponds to actual use e.g. "On what proportion of the times when it would be useful did you invoke it?"

Check for sources of information: You can also ask them to name the people they are most likely to chat with about, or comment on, commands and features of this interface. See if you can identify social clumps of usage/knowledge by correlating knowledge as measured by the checklist with these links between names.

Analysis
You will have data on: total number of commands, which known, needed, used, and perhaps the source of the knowledge.

Known - Needed -> info. flood i.e. danger of distracting user with useless commands.
Needed - known -> info. delivery problem i.e. users haven't discovered commands they need
(Needed & known but not used -> reminding problem: users don't remember at the right moment.)
Total - Need (or Total - Used) -> too many features?

Bibliography See questionnaire bibliography

Summary of properties

Whose judgement? user's
Internal / external surface measure: Internal — ask the user
Cost to investigator cheap: the time to adapt the standard questions, copy in the list of commands, duplicate and handout the checklist.
Cost to each user 2-15 minutes
Retrospective or on the spot retrospective

Typical measure Category
Typical testing episode Just this instrument
Typical result calculation See above: compare the answers in different columns for a single item (command) and a single user.
Typical report goals Market survey, background information in fixing bugs, requirements capture for next version of software

Example:
System 7 Finder Checklist

This checklist is inquiring about the commands in Macintosh system 7 Finder: which are needed, which used, which known to exist. Down the left hand side are the names of the commands. Each column represents a separate question, explained at length here. Fill in each box with a number or a tick representing your answer to the question for the command on that line.

Q1. Did you know this command existed? (Knowledge) Tick for yes

Q2. How often do you have any need for the command? (Need)

Even if you have never used it, estimate how often it would be useful if you did.

0=not needed
1=needed less than once a week
2=once a day or less
3=once an hour or less
4=every 10 minutes
5=more often

Q3. How often do you actually use the command? (Use)

0=not used
1=used less than once a week
2=once a day or less
3=once an hour or less
4=every 10 minutes
5=more often

Down the left hand side of this page is a reduced version of the checklist: it should be twice this size to be convenient for users to fill in.

Instrument 5. Questionnaire

Primary function
To assess preferences and pleasure in using an interface, tap knowledge, ask about the sense of competence, where there are large numbers of users and the investigator wants a method that is cheap in time and and other resources, and needs only relatively coarse results.

Any question may be asked, but it turns out that questionnaires are best suited for the above kinds of question. Focus groups may be used for a fuller probe into such attitudes. The main alternative or supplement is semi-structured interviews; where possible it is often a good idea to debug the questionnaire by administering it as an interview.

Basic idea
Questionnaires provide a quick and easy way of allowing to the user to respond to pre-packed items in the form of questions, or statements to agree or disagree with. This is the cheapest way of gathering information, but the information is correspondingly limited, and suitable only for some kinds of application. Once the questionnaire is designed it can be used in large numbers, without the presence of the investigator.

Method
The basic method of questionnaires is to make each item simple and without ambiguity.

Two things have to be designed: the questions and the response scales. For any one questionnaire form it is usually best to keep the format of the questions and the response scales standard.

Questions can be about anything. But they must be simple, not compound ideas or clauses joined by an "and" or an "or". Otherwise the responses become uninterpretable. It is, on the other hand, acceptable to ask a series of closely related simple questions — indeed this is the method that experienced psychometricians use. They can then check statistically, over the responses of a set of subjects, to see how much each of the simpler questions typically contributes to a more complex underlying entity.

As to response scales, these can vary from simple yes/no category responses to an analogue scales, e.g. a 10 cm line, with anchor points at each end. An "anchor point" is a verbal description indicating to the subjects a defined point on a scale. Verbal anchor points are usually necessary for every kind of scale. An example of the lowest point on a scale of preference is: "The worst I have ever experienced".

Typically a scale with three, four or five response categories is adequate. Psychologists have found that for most purposes increasing the number of points on a scale beyond seven does not increase accuracy, so if you use more response categories than that, remember that the margin of error is likely to be at least 15%.

If you are making a scale with two extremes and a midpoint (a bipolar scale), e.g. from the least to the most of something, make the scale symmetrical and have an odd number of response categories with a well defined mid point. E.g. a five point scale asking subjects to agree or disagree with a statement might have the response categories:

strongly disagree | disagree | don't know | agree | strongly agree.

Unipolar scales, e.g. going from "not at all" to "every time", need not have an odd number of response categories.

Analysis
Take simple summary statistics of each response: mean, min, max, standard deviation. Perhaps a measure of skew. Depending on the set of questions, further statistical analysis may be possible e.g. comparing the responses of different age groups. Complex questionnaires are often analysed using sophisticated statistics.

Bibliography
Brynner, J. & Stribley, K.M. (1979) *Social research: principles and procedures.* Longman.
This is an edited set of articles for social science students on many aspects of research design. It includes articles on how to word questionnaires, virtues of checklists versus questionnaires etc.

Coolican,H. (1994) *Research methods and statistics in psychology* ch.9 (Hodder & Stoughton: London)

Oppenheim A.N. (1966) *Questionnaire design and attitude measurement*. Heinemann.

For references on statistics, see the section on experiments as an instrument.

Summary of properties

Whose judgement? User's
Internal / external surface measure: Internal — ask the user
Cost to investigator Small: only takes a few seconds to send out each copy. But designing and piloting a questionnaire may take a long time. Still, the cost per subject for large samples is still small.
Cost to each user Usually small, but possibly up to an hour for large questionnaires.
Retrospective or on the spot Retrospective

Typical measure Ordinal or category measure of attitude
Typical testing episode May be combined with any other instrument
Typical result calculation Summarise responses across subjects using statistics
Typical report goal Any
Problem: low response rates unless administered verbally; and hence problems of sample bias.

Example: Word Processing questionnaire

1. How confident are you that you could write a letter using Word with an impressive and business-like appearance?

Circle one number on the scale below to indicate your confidence:

Extremely unconfident	0-1-2-3-4-5-6	Extremely confident

2. How confident are you that you could write a letter using your ordinary handwriting with an impressive and business-like appearance?

Circle one number on the scale below to indicate your confidence:

Extremely unconfident	0-1-2-3-4-5-6	Extremely confident

3. Are you content with way the Apples on the 5th floor are maintained?

Circle one number on the scale below:

Very unhappy	0-1-2-3-4-5-6	Very happy

4. How long an extension if any should be allowed in project deadlines?

Circle one of the following:
None - a few hours - a few days - a few weeks - no deadline

Instrument 6. Semi-structured interview

Primary function
The semi-structured interview has become one of the most important methods in social science. It produces quantitative data of far higher quality for most purposes than questionnaires. This occurs because you can go on talking to the subject in what ever way seems natural and relevant until you are sure s/he understands what you mean, and until you are sure that s/he has either told you what you want to know, in a form that you can categorise accurately, or that the person does not have the information you want.

At the same time, because users talk directly about their experience with the interface, the investigator can get a good qualitative sense of what it is like for them, sometimes almost as good as can be obtained from think-aloud protocols, though obviously the results will be affected by forgetting, and elaborations, in ways that think-aloud methods are not. Alternatives, then, are questionnaires and focus groups for investigating relatively permanent attitudes and issues; and think alouds for specific events and problems.

Basic idea
A fully structured interview is one where the interviewer speaks only a fixed script: essentially a spoken questionnaire. An unstructured interview is open-ended, so that the responses are not comparable to each other. The semi-structured interview has fixed (structured) topics and ultimate response categories, but the actual words used by both interviewer and subject are flexible.

The basic idea is:
i. to conduct interviews in which you have fixed the agenda, with preset categories of response that you will score for, with ready rehearsed probes to remind the subject of important things to consider,
ii. to be open-minded, talking without a script until you can categorise the subjects response accurately, and also with a view to recording the unexpected.

Method
At the same time as being informal, the interviewer must be careful not to put words into the subject's mouth. Interviewing is a skill which needs training and practice. At first it is best to tape record interviews, and have them listened to by people experienced in interviewing.

An interview schedule is made up of four components.
(a) the questions, in forms of words that you will ask the subject
(b) sets of probes
(c) sets of response categories
(d) boxes for scores, which are typically categories of response, or quantitative estimates

Interviews invariably need piloting and practising before you go to the users you are most interested in.And if there will be more than one interviewer, there will need to be training and standardisation among the interviewers.

The aim is to try to get either quantitative measures (e.g. how long, how often) or behavioural indices, or both. These could be done with questionnaires, but the problem then of whether each subject is applying the same standards often prevents useful conclusions from being drawn.

Analysis
As for questionnaires.

Bibliography
J.E. Cooper et al. (1977) "Further studies on interviewer training and inter-rater reliablilty of the Present State Examination (PSE)" Psychological medicine vol.7 517-523.
G.W. Brown & T. Harris (1978) Social origins of depression (London: Tavistock). Especially appendix 5.
The pioneering work on making this technique objective and reliable was done in the psychiatric field. Ignore the psychiatric content, but attend to the method.
Draper, S.W. & Anderson, A. (1991) "The significance of dialogue in learning and observing learning" *Computers and Education*, vol.17 no.1 pp.93-107.

Summary of properties

Whose judgement? investigator
Internal / external surface measure: Internal — ask the user
Cost to investigator A few minutes up to an hour for each subject: expensive.
Cost to each user A few minutes up to an hour.
Retrospective or on the spot retrospective
Prompt type: Investigator's dynamic judgement about how to prompt
Typical measure Ordinal or category measure of attitude
Typical testing episode May be combined with any other instrument
Typical result calculation Summarise responses across subjects using statistics
Typical report goal Any

Example of a semi-structured interview

1. How confident are you that you could write a letter using Clarisworks with a business-like appearance?

Probes	Categories	Score
What will they think at a glance?	Couldn't do it at all	0
Will it look professional?		1
	would not look good	2
		3
	words OK, some details of format poor	4
		5
	Could make it perfect	6

2. How confident are you that you could write a letter using your ordinary handwriting with an impressive and business-like appearance?

Probes	Categories	Score
What will they think at a glance?	Couldn't do it at all	0
Will it look professional?	would not look good	2
	words OK, some details poor	4
	Could make it perfect	6

3. Are you content with way the Apples on the 5th floor are maintained?

Probes	Categories: frequency	Score
Does the system work well?	Something almost always wrong	0
Long delays?	Goes wrong >50% of the time	1
No apparent response?	Goes wrong <50% of the time	2
		3
Categories: type of complaint		4
No-one to help	Things went wrong only 1 or 2 times	5
People unhelpful	Perfect	6
Takes too long to get anything fixed		
Very good service		

4. How long an extension, if any, should be allowed in project deadlines?

Probes	Categories	Score

What if you're ill?	None	0
Extensions just mean you	up to 24 hours	1
won't keep up with other work?	up to 1 week	2
	up to 1 month	3
	No deadline = Till exam time	4

Instrument 7. Experiment

Primary function
We often want to measure some aspect of performance with a user, or small group of users. We might then also want to see whether this measurement is associated with some particular aspect of the interface, e.g. speed and errors for doing an operation the same if the relevant information is presented in this way or that.

Secondly we might wish to discover whether one system is better than another, or than some baseline, on a particular quantitative dimension. This method can be contrasted with think aloud protocols, where one gets a great deal of information from a single user, but at the same time can be very influenced by the particular characteristics of that user, who may not be typical. The experiment is a search for objective measures that are typical of an interface design, independent of biases of the investigator or idiosyncrasies of the particular people who are sampled as users.

Basic idea
Since there is inevitable variability between users, there is limited point in careful quantitative measurement of the performance of any single one. Usually we need several. From the several performances we calculate mean scores for a particular type of user. Even then if we measure the mean for a group of subjects using one interface design, and compare it with the mean using another design, we will probably not know intuitively whether the difference is large enough to rely on.

The idea of doing an experimental trial, therefore, is to control the experimental conditions, make the measurements, and using significance tests calculate the probability that any difference we observe can be attributed to features of the interface the users have used, and is not just due to extraneous factors, individual characteristics of users, measurement errors, or other uncontrolled factors.

Caution
Though experiment is the most favoured method of experimental psychologists, as the ultimate generator of reliable quantitative knowledge, its use is restricted. It is only worth doing if a small number of reliably measurable variables is relevant, and when there is a reasonable chance of superiority of one system over another as measured by these variables.

Experiments are good at generating facts that are free of speculation and bias. With the right skills is possible to measure aspects of human performance quite accurately — e.g. do people read screens faster with text displayed in this typeface or that one, does this interface feature produce more errors of some kind, than that one.

The reason experiments are not relevant to most evaluation problems is that there is nothing in experimental method which tells one which facts will be important. This is particularly problematic in HCI because there are thousands of "facts", thousands of quantitative comparisons, that could be generated for any interface. It is vital to establish, before doing any controlled experiments, what the dominant factors are, and this cannot be done by experiments themselves. If this is not done, then the results will be true but wholly unimportant, as in normal (i.e. uncontrolled, non-laboratory) situations, the effects found will be much smaller than, and so swamped by, other factors. Landauer (1987) attributes to this the failure of academic cognitive psychology to make a theoretical impact on HCI.

Other drawbacks are as follows. First the method will only allow discrimination between like and like, e.g. comparisons within some local region. It is not usually good for multivariable comparisons. Secondly, such comparisons only tell one whether a reliable difference between the systems tested exists or not, they do not say whether this difference is important, or whether its size means much. The experiment is expensive in time and other resources. It also requires the development of a considerable array of skills on the part of the investigator. It requires intuitions about whether this particular measurement and comparison will be informative.

In the end, though, it is only by properly designed experimental comparisons of this kind, that one can say this feature is better than that. In the end also, it is only by using experimental methods that issues about what actually causes what can finally be settled.

Method

Two basic types of measure of performance are typically useful, those based on time, and those based on the number or errors in a performance (or conversely number of items correctly performed).

Assignment of users to groups. The simplest experiment is one in which there are just two conditions. All analyses of experiments rely on the a very careful assignment of subjects to conditions, which must be effectively random: not haphazard, but mathematically random.

Since we humans have very poor intuitions about randomness, and cannot generate random sequences the only way of conducting a random assignment to conditions is to use a mechanical means, tossing a penny, referring to a book of tables of random numbers, generating a pseudo-random sequence with a computer algorithm...

Pilot experiments and planning. Experiments do not work well without careful planning. To conduct an experiment without having planned it, and practised it until it goes like clockwork is a complete waste of time. One must test and refine each sub-procedure on subjects who will not themselves be in the main experiment. Then a dress-rehearsal is needed of the whole procedure to see that all the parts fit together.

Analysis

Can be sophisticated and statistical, since an experiment allows detailed comparisons.

Bibliography

Robson, C. (1990) "Designing and interpreting psychological experiments" ch.17 pp.357-367 in Human-Computer Interaction (eds.) J.Preece & L.Keller (Prentice Hall)

Landauer, T.K. (1987) "Relations between cognitive psychology and computer system design" ch.1 pp.1-25 in Interfacing Thought (ed.) J.M.Carroll (MIT Press: Cambridge, Mass.).

Miller, S. (1984) *Experimental design and statistics.* London: Methuen New Essential Psychology.

Robson, C. (1973). *Experiment, design and statistics in psychology.* Harmondsworth: Penguin.
The books by Miller and by Robson are minimal statistics books aimed at undergraduates with little knowledge of maths, to allow them to design an experiment and analyse it statistically.

Statistics

Ericson, B.H. & Nosanchuk T.A. (1979) *Understanding data: An introduction to exploratory and confirmatory data analysis for students in the social sciences.* Milton Keynes: Open University Press.
This is one of the very best books on statistics, written by two people who were students of John Tukey, who did much to make statistics into a method that could be used to explore data.

Siegel, S. (1956). *Non-parametric statistics for the behavioral sciences.* McGraw-Hill.
Still the favourite book on non-parametric statistics, a model of its kind.

Examples of Experiments

Baxter, I. & Oatley, K. (1991) "Measuring the learnability of spreadsheets in inexperienced users and those with previous spreadsheet experience" Behaviour and Information Technology vol.10 pp.475-490.

Bewley, W.L., Roberts, T.L., Schroit, D., and Verplank, W.L. (1983) Human factors testing in the design of Xerox's 8010 "Star" office workstation *Proc CHI'83: Human factors in computing systems* 72-77 (ACM press). Also in ch.18 pp.368-382 in Human-Computer Interaction (eds.) J.Preece & L.Keller (Prentice Hall)

Carroll, J.M., Smith-Kerker, P.L., Ford, J. and Mazur-Rimetz, S.A (1987/1988). The minimal manual. *Human Computer Interaction*, 3, 123-153.

Card, S. English, W. & Burr, B. (1978). Evaluation of mouse, rate-controlled joystick, step keys and text keys for text selection in a CRT. *Ergonomics*, 21, No 8.

Karat, J., McDonald, E. & Anderson, M. (1986). A comparison of menu selection techniques: touch panel, mouse and keyboard. *International Journal of Man-Machine Studies*, 25.

Summary of properties

Whose judgement? instrument maker (e.g. stopwatch)), or investigator.
Internal / external surface measure: Mainly external — observe the user
Cost to investigator Often 1-3 hours for each batch of subjects. Plus a lot of piloting.
Cost to each user Often 1-3 hours.
Retrospective or on the spot On the spot
Prompt type: Hopefully, only carefully controlled experimental instructions

Typical measure Usually pre-determined fixed, behavioural measures e.g. time, number of errors. But can also do e.g. an interview for non-behavioural and/or open-ended measures.
Typical testing episode An experiment *is* a testing episode in effect
Typical result calculation Statistical
Typical report goal To compare two things
Problem: designing an experiment that is relevant to the real issues.
Advantage: potential for reliable quantified generalisations across users.

Comparing instruments: how they merge into each other

Think-aloud protocols can merge into SSIs (semi-structured interviews) and experiments and field studies. They may be entirely open ended, but as the investigator becomes more focussed in tracking down some particular problem, so they may (1) set a definite task in order to elicit the problem quicker — this makes it more like an experiment; (2) ask probing questions with some focus, thus making it more like an interview. Thinkalouds observe the task with verbal extra data; while SSIs use recall with the machine and task as an optional aid to prompt recall. (3) Another variable is the degree of naturalness in the conditions. This is partly about what tasks are set (are they just those that this subject and/or typical subjects would be doing in their work?). But it is also about whether the study is done at the subjects' workplace (on their terminal, in their office), or not; and whether the investigator waits to observe the tasks that are part of their job, or whether they are doing it as an extra activity. Complete naturalness makes it a field study, complete artificiality an experiment, and the usual case is in between.

A fully structured interview is one where the interviewer speaks only a fixed script: essentially a spoken questionnaire. An unstructured interview is open-ended, so that the responses are not comparable to each other. The semi-structured interview has fixed (structured) topics and ultimate response categories, but the actual words used by both interviewer and subject are flexible.

An experiment is really a testing episode as well as an instrument. All the other instruments may be applied within it: and questionnaires often are, in addition to behavioural measures.

A questionnaire is usually applied to a) attitudes and affect b) as in checklists, to reliable memory of stable habits rather than one-off events. But questionnaires can be open-ended (and so are comparable with thinkalouds).

Diaries may be used for debugging: if so, most likely to be followups, and focussed: verging on interviews or questionnaires, rather than thinkalouds.

Diaries can also be used however for counting events or behaviour. They are then like behavioural observation by the experimenter. In this respect, they really are like thinkalouds; but a) the probes are more likely to be specific than general b) the event is defined, so it is not open ended. However the focus is by event rather than by task.

Questionnaires often have redundant questions to provide an internal validity / reliability check. In contrast, SSIs typically have a single topic but redundant probes.

The deep issue is behaviour vs. asking the user. One can get at most things via either method in principle, but in practice you need both despite the large area of overlap. If you ask the user you are relying on their memory, and then the issue is on the efficacy of various prompts, from none, to probes, to careful visual prompts, to having them view themselves on videotape or to do the task to aid recall.

Testing episodes: Packages of instruments (level 3)

In practice for any one kind of problem a package of instruments will be needed, and further examples will be given in the next section where the types of measurement study are listed. For instance a designer may put together a package of think-aloud sessions, interviews, and diaries to provide feedback in the development and debugging of a system. A product manager may want market research questionnaire and interview data, and the results of a more formal comparative experiment on prototypes. Thus someone training to become a professional evaluator or contract researcher may wish to practice as many methods of the kind we have outlined as possible for different kinds of interface, to be in a position to offer specialist consultative advice, and comparisons across a range of systems.

In general, the different instruments will be used in different combinations for different purposes. Each instrument can, moreover, be used to conduct cross checks on others.

The testing episode however involves determining many other things. In general, choices are made of which users, which machine(s), and which environmental factors will be used. Under the choice of user, the major variables include: what permanent characteristics will they have (e.g. age, gender, physical abilities), what prior knowledge of various kinds will they have, and above all which tasks will be set. (Tasks may be regarded either as a feature of the user, since they are a mental state, or as an independent variable since to a large extent any user can be set any task and will probably cooperate. However this is only an approximation, since a subject's decision about what to do when instructed to "produce a business letter" by an experimenter may differ both from other subjects and from what they would really try to do in a real work situation.)

1. Users: On whom are the measurements made?

There are indefinitely many types of user, and contexts in which a system will be used. But for practical purposes we must define a manageable set. One frequently used distinction is between naive users, intermittent users and expert users. We believe that although this distinction can be helpful, it can also be somewhat superficial as different groups of users may have different areas of knowledge. We have found it useful to assess users' prior expertise separately in three areas: in the task domain (have they ever used another spreadsheet?), in the machine (have they ever used this kind of computer before? a mouse? etc.), as well as in the particular program to be tested.

Ideally, one might also want to be able to assess asymptotic performance on a system by highly practised experts, and use such measures in comparative tests among different systems. In practice this is often expensive or impossible.

In terms of a framework of measurement, we need to choose carefully the users on whom we will make measurements, as how we choose them will affect the generality of the conclusions we can draw.

2. Tasks

If you are going to do on the spot observations of a user (e.g. in an experiment), then what you see will depend on what tasks they attempt. In a study at their work, users may just do whatever their work dictates. However if it is a new interface for them, then there is the question of what task you set them, or what they come up with if you don't specify one. In fact these apparent alternatives can be closer than you expect: if you do not set them a task, they may select one partly to fit in with what they imagine is appropriate to show you e.g. they may not try out computer games or read news, even if they normally would. On the other hand, if you do give them a task through a verbal instruction, they will interpret this according to their own ideas about tasks (and this can be rather different between subjects). For instance if you ask them to type a letter on a word processor, how much formatting they do will depend on their habits with word processors and what they know about letter formats. In fact it has been found that the only way to get subjects to do exactly the same thing is to dictate every detail of the task (which is then unrealistic since normally users decide these details themselves).

If you wish to test an interface, then you have in fact two conflicting goals: to observe not only how the interface behaves but which parts of it a user will normally and spontaneously use, and to observe how every possible part of the interface behaves. In other words, you would like to see normal user behaviour, both as data in itself, and to gather frequency information on which things get used often; but you would also like to test the interface artificially to check every part of it. The former implies setting no task, while the latter requires you to set a series of tasks that will together exercise every part. In practice you may wish to do both; perhaps setting no particular task in the first part of a session, and then producing a set of test tasks for a second part.

3. Machine, Environment (Circumstances). An important aspect of measuring is the circumstances. If the observed action is not performed in the normal situation it may not tell you much about how the interface performs in ordinary use. This is the danger of all experiments as opposed to naturalistic observations. Overall, an investigation probably needs to balance some naturalistic and some controlled observations. Basically naturalistic observations can tell you unexpected things; and it can tell you about the normal occurrence, rate, and function of some event. Experiment can tell you about causation, about the dependence of an event on various factors.

For instance, if users normally have to work in an office with constant interruptions from the telephone, then running an experiment away from the office may show much better results than can normally be achieved. On the other hand, if they are used to getting help from colleagues, then finding that they cannot use the help system is less significant than it might seem. Running tests on the right machine is equally important of course. In these days of networked machines, it is no longer trivial to arrange for this, since using the same "model" does not at all mean that the user will see the same performance or file environment.

Comparability and realism

Besides deciding on how to set these variables, another main concern at this level is comparability: the degree to which different instances of the measurement are made comparable. This crucially affects what conclusions may later be drawn by comparing measurements. There are two logically independent considerations, which however are usually antagonistic so that only one can be optimised: are the variables held constant across cases (so that measurements are strictly comparable), or not. The other is realism or "validity": are the conditions studied representative of those in normal life. Generally in an experiment, conditions are controlled (held constant) as far as possible, at some sacrifice of realism and validity. In a field study, realism is maximised, but only one condition is studied (the one that obtained during the study), so you cannot tell whether and how outcomes might change if different users or tasks (say) were used. Thus there often seems to be a single variable varying from a lab. study to a field study, with both comparability and validity depending on it.

Nevertheless with care it is sometimes possible to achieve a reasonable position on both issues. For instance in studying a spreadsheet, you might begin by a survey of actual spreadsheet users in their workplaces to discover what tasks they commonly do. Then you could run an experiment under controlled conditions, but where the subjects are set tasks matched to those that the survey had shown were realistic.

Summary of dimensions of testing episode

Comparability: Is the set of instances under each choice uniform (controlled)?
Validity: Are they natural (representative of the intended set)
Laboratory study <—> Field study
Coverage of the potential space of bugs

Results (level 4)

Often there are theoretical quantities or conclusions not directly delivered by an instrument. These need to be calculated here. An example are the conclusions about redundant methods, or badly advertised features which might be concluded from checklist results. From a practical viewpoint, having a results calculation method worked out e.g. a spreadsheet layout can make a big difference in speed and convenience. In general we have commented on results methods within the section on each instrument.

There are three broad kinds of thing that might be done:
1. Transforming numbers (e.g. scaling, doing a log transform)
1.2 including combining two direct measures to make another one e.g. subtracting two times.
2. Describing sets of numbers. This mainly corresponds to exploratory analysis (see below). A central idea is to see a particular data set as an example of a distribution, and to characterise that distribution by its type and by some parameters e.g. mean and standard deviation. The idea is to replace many particular points by a description of the overall character of the set.
3. Comparing two sets. In particular, calculating the probability of their being samples from the same or different sets — i.e. deciding whether they are significantly different.

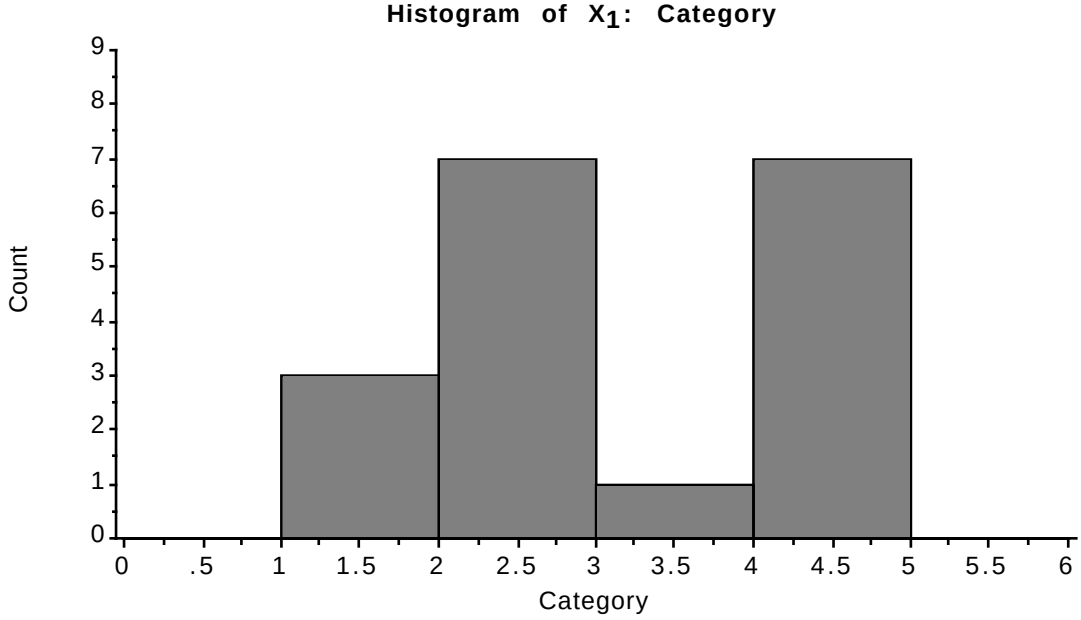
Presentation of quantitative data of any kind is usually done by tabulations, histograms, pie charts, graphs etc. The goal here is to present visually just those features of the results that are important, relevant, and summarise what the reader might need to know, while maintaining the quantitative aspects of the data, e.g. mean scores, numbers of users, etc.

Another general issue here is, where possible, to compare results from one instrument with those from another. For example, an interview can be done using the same questions as a questionnaire. If the average answers are much different from the two instruments, this is a reason to suspect that one or the other instrument was not well administered (e.g. selection bias in the subject sample).

Statistical analysis of data

When the data are gathered they must then be presented to oneself in a form that will make the results visible, and easy to understand, easy to brood over, and easy to check any mistakes in transcription or elsewhere. See, e.g. the book by Ericson & Nosanchuk (1979) on exploratory analyses in the reference list.

The purpose of exploratory analysis is to present the data to oneself and others in such a way that its underlying patterns become clear. Thus imagine either observing responses by users during think aloud sessions, or collecting such responses from an interview. Imagine also that these responses have been sorted into four categories — then a good way to get a sense of their relative frequency is in the form of a histogram. E.g.



Other exploratory methods similarly are designed to display patterns in tables or diagrams in such a way that important pattersn become visible, emerging from the clutter of individual observations.

Then there is confirmatory statistical analysis. With instruments 3 to 6 these analyses are usually tests of cross-tabulations, correlations, tests of differences between means for different conditions etc. (For the idea of testing differences, see the following paragraphs, and the introductory statistics books in the reference list.).

An experiment, instrument 7, will typically be based on the testing of a hypothesis. This in turn implies the testing of differences between outcomes, for example between an experimental condition and a control condition, which one would expect to be different if the experimental condition had had an effect.

Statistical methods exist for determining whether any such differences that are found are large enough to take seriously. The convention is that if a difference between outcomes for different conditions that has a probability of occurrence by chance of less than one in twenty ($p < .05$) this difference is described as "significant at the five percent level". It implies that the experimental manipulation made a difference. (See e.g. the introductory statistics books in the reference list.)

These statistical methods are called significance tests.

They can be either "parametric" or "non-parametric". The former means that they are based on estimating parameters, such as the variance, of statistical distributions of known properties. Such tests are typically used when the measurement scales have proper mathematical properties (e.g. when a score of 4 really does mean twice as much as a score of 2). These tests include t-tests and analysis of variance.

Alternatively there is another set of methods called "non-parametric" which do not rely on the distribution of data having such closely defined mathematical properties. These tests typically require outcome measures to be converted into ranks, e.g. the highest score from an experimental measurement gets rank 1, the next highest, rank 2, and so on. Such tests include the Mann-Whitney U test, the Wilcoxon test, and the Friedman test. (See e.g. the book by Siegel, in the reference list.)

The underlying logic of most significance tests is to form a ratio or fraction, of the difference between the means of outcomes for people in the different experimental conditions, divided by some measure of the variation of outcome measures for people in the same experimental condition. E.g:—

mean of experimental group - mean of control group / variation of score within each group.

or, more generally:—

difference due to the experimental manipulation / estimate of measurement errors and other noise

Then there are tables or calculations that will allow one to see whether this ratio indicates that the difference attributable to the experimental manipulation was larger than could have been expected by chance, where "chance" means because of the errors of variation among individual subjects each giving a somewhat different estimate of the the underlying entity that you would like to know about, measurement error etc.

It is possible to do many of the calculations to make such tests by hand, with a pocket calculator or spreadsheet, using the recipes supplied in any of the statistics books listed in the references. It is by far preferable, however, to do statistical calculations using one of the several statistical packages available on either micro-computers or mainframes. For Macintosh computers we recommend StatView, for mainframes or IBM PCs SPSSx. The former makes use of the Macintosh interface, though you will also need a statistics book to understand the tests being used. The latter is the most popular mainframe package used by social and behavioral scientists, and is supported by particularly good documentation, including full and clear discussion of each statistical test available.

Both types of package allow one to tabulate one's data in a systematic way, and then manipulate them, perform various kinds of test, and produce various kinds of table and graphical output.

Kinds of result

Discuss the kinds of result we want, and produce. On the one hand, comparative measures; on the other hand, lists of bugs or goals or supertasks or complaints: i.e. things whose content is valuable, rather than whose number.

Summary of dimensions of result calculation

Comparability: may the measurements be meaningfully combined, or not?

Producing a report (level 5) (Goals for measurement studies)

The gap between measurement and decision

The reason we have described evaluation as based on measurements, is that measurements are not themselves judgements about what to do, either for design, purchase, or other kinds of decision. This requires putting the measurements into the context of a set of goals that are not themselves part of the measurement process. Measurements cannot themselves tell one what to do.

Types of report

When an evaluation has been made, typically a report has to be given. What kind of report might actually be wanted? One common and important need is (1) for a report which will allow the person reading it to make a purchasing decision. The situation is that the decision to purchase something has been taken, and now information is needed comparing alternative products. A manager is not likely to want to be told what to do by a self-proclaimed expert. As we can see from the reports in the Consumer Association publication "Which?", even private consumers prefer a table listing numerous properties of the alternative products, allowing them to decide how to weigh the various properties for their own purposes in making some final decision. Managers are not likely to require less information and more hand-holding than this.

Similarly (2a) managers in charge of designing and producing products are likely to want to make the decisions themselves which combine reports on market demands and opportunities with reports on the properties and performance of designs produced by their company. The business of those who "evaluate" designs for such managers is to produce the latter kind of report, not to second-guess market research or to dictate advice directly. The measurements here are likely to be on a single design, using relatively fixed standards. Just as there are benchmarks, and specifications, technical standards etc., for speed, capacity performance under different conditions for hardware, we may hope that computer manufacturers will begin to take up the idea that the properties of interfaces can be specified in relation to users. We believe that such benchmarks will be to the benefit of both manufacturers and consumers, in the same way that hardware specifications have been, and (2b) constitute another type of report. So learning times for new users, data on user preferences, asymptotic performance, and data on typical user competence may gradually become available, and also be used in assessing the suitability of interfaces for a given purpose. This corresponds to a second type of purchasing decision (3), where the decision is whether to purchase a computer system at all, and the performance of the candidate system must be compared with the individual needs of the purchaser.

Another kind of report (4) is at a higher level of generality (closer to the questions that academic psychologists are used to addressing). An example might be to determine whether adaptive interfaces are worthwhile. Here again, what is really wanted is not a report of whether one adaptive user interface is better than one non-adaptive interface, but the tracking down of as many differences as can be found, plus reliable results on some features of obvious prior interest (e.g. speed of learning or productivity), preferably on a number of interfaces rather than a single representative of each type. Again, what is wanted is measurement and reporting of numerous properties. Only in the light of this will readers of the report be able to decide how to discuss what is "worthwhile" in this context.

In the area of constructing programs, there are potentially several kinds of report: pre-design requirements capture (5), debugging an interface under construction (7), benchmark measurements on completed designs (2b), and perhaps a report on the properties of a completed design in relation to competitors' products (1), its own properties (2a), and customer demands (8).

Pre-design requirements capture (5) can be approached in numerous ways, many of which depend more or less closely on users' experience of existing systems that the new design is to replace such as focus groups, field studies, and surveys of command and feature usage (see 6 below). Perhaps best of all if resources permit is the use of early prototypes, so that users can try out the new proposals and their reactions studied in think alouds, and debriefing interviews and focus groups. This latter approach avoids having to depend on users' very limited ability to imagine what new designs would be like in practice.

Another kind of report (6) looks at how a machine is actually used (as opposed to how its designers may have expected it to be used). This may be for managers to establish its usefulness, or to guide revisions or even new designs. It might list the tasks users choose to carry out, or the comparative frequency of different tasks, under natural conditions. A variation on this is to look at the tasks and methods chosen by users at different levels. For instance at a low level, the comparative frequency of use of menu and keyboard commands (when both are available) might be measured; the relative frequency of use of different commands and features; the tasks

which people set themselves (e.g. on a word processor, letters versus memos, versus papers, versus whole books). And finally the "supertasks": the surrounding considerations users may have. For instance, when they quit an application do they usually want to save the document? do they want to back it up immediately on a separate, extra floppy disk?

Another goal (7) for measurement is to discover the bugs in a user interface. If the aim is to build a perfect interface, then a simple detection of the bug is enough. In addition, it may be required to search out all bugs, and so to exercise the interface comprehensively by setting users tasks, even if unnatural, that will cause them to use all parts of the machine. If, as is often the case, there are only resources to fix some bugs, then such a report should also give estimates of the frequency of occurrence of the problem in normal usage, together with how much it costs the user each time.

There is also (8) the business of determining user attitudes and values. These can sometimes be measured as part of another study, but are worth mentioning separately as different instruments may have to be used. There are both positive and negative aspects to this: the utility a person feels they gain from the work or fun had with a machine, and the affective (emotional) costs in mental strain or dislike. These should be separately measured. They are ultimately seen in their effect on user choice (of whether to use a machine, or which one to purchase), but only in their net combination or sum. However a designer should know if there are aspects of the design which the user dislikes or finds punishing, as perhaps these can be remedied without affecting the positive utility (which is all that keeps the user loyal currently).

Finally, (9) it would be possible to use this approach to do comparative measurements on users, either to grade users, to certify their level of training, or to compare the system's performance with different classes of users.

Considering the range of functions that performance measurements serve suggests that measuring, rather than value judgements, is the heart of the matter; that almost always such measurements should be reported rather fully (not used to make a judgement and then hidden); and that such measurement is a skilled activity in its own right, that can usefully be considered as a separate subject. Putting this another way, we can say that evaluation properly has two parts. One is measurement. The other is assessing measurements in relation to goals.

Other ways of describing alternative report types

In the literature, different goals for measurement, and hence different report types, are described by labels such as:

formative — to help create or modify the design
summative — describe the performance of a fixed design
illuminative — identify factors that are important.

Summary of dimensions of goals (report types)

Where in the design cycle is the study done? {illuminative, formative, summative?}
(How complete a prototype is needed?)
Comparability: does the report's goal require comparison of measurements?