# The Virtual Laboratory Infrastructure for Controlled Online Experiments in Economics

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*Abstract*

The goal of this paper is to provide an overview on the *Virtual Laboratory* infrastructure for controlled online experiments in economics. We summarize our experience gained from performing several economic experiments on the Internet. The experiments we have run range from electronic markets to individual decision making. From there we synthesize and evaluate the methodological issue of experimental control in performing economic experiments on the Internet. The paper discusses IT-based solutions to maximize control over subjects and the environment when conducting experiments online. As a result for further exploration we sketch the design of an infrastructure that allows the automated execution of Internet experiments including marketing of experiments, control of application and participation, payment system integration, and evaluation of results.

**Keywords:** Internet experiments, Internet services, experimental economics, methodology.

# 1 Introduction

The Internet provides a natural testbed to conduct experiments with human subjects. Early psychological online studies proved that it was not only possible to conduct research online (Krantz, Ballard & Scher 1997), but that it was also feasible to collect large samples of quality data in a short period of time (Birnbaum 2000). Inspired by these early advances in psychological online research experimental economists started to run experiments via the Internet (Budimir & Rieck 1998, Baier, Bolle, Buschbaum & Swiniarska 1997, Lucking-Reiley 1999, Anderhub, Müller & Schmidt 2001, Shavit, Sonsino & Benzion 2001, Drehmann, Oechssler & Roider 2002).

Internet experiments have various advantages over computer–based laboratory experiments:

1. higher participation rates
2. feasibility to conduct experiments with long duration (e.g., days)
3. access to a more diverse subject pool (demographically, culturally)
4. higher ecological validity (artificial laboratory vs. familiar environment)
5. avoid experimenter effects
6. feasibility to conduct experiments without an expensive laboratory setup
7. automation of many experimenter tasks
8. Internet experiments run in the laboratory, but laboratory experiments do not run via the Internet, at least most of the time

The main drawback of the open environment of the Internet is that the experimenter looses some control. One aim of this paper is to provide IT-based solutions to some of the following problems

1. less control of subjects (double participation, group decision, drop-out)
2. less control of environment (use of aids, quality of network connection)
3. immediate payment (currently not feasible)

Internet experiments can be conducted in a more or less controlled environment. Some experiments are conducted close to the standards of laboratory experiments (Anderhub et al. 2001, Shavit et al. 2001) with values induced to participants (Smith 1976) and computerized user interface, some are conducted less controlled with home grown preferences and e-mail communication (Lucking-Reiley 1999). It seems that many variations between both extremes are possible. We are aware that the proposed IT-solutions to increase control might exclude participants and might not attract a representative subject pool. Most experimental economists are more concerned about control than about representativity of the subject pool since the theories which are tested in general do not make predictions with regards to the demographic distribution of the economic agents (Camerer 1997).[1] Still, the subject pools

[1]Online research in psychology is more concerned about representativity of their subjects.

of Internet experiments are far more diverse than the usual student subjects in the lab (see Anderhub et al. (2001) for details).

The goal of this paper is to provide a technical guide for experimental economists who want to conduct a controlled online experiment. This paper is not about on how to implement an online experiment, other authors have dealt with this topic (Kirchkamp 2000), rather on how to technically design and organize an economic Internet experiment in the light of maximizing experimental control.

Other online infrastructures for economic experiments exist. The Veconlab at the University of Virginia provides a service to run economic experiments for interactive learning. The site offers about 30 different experiments which can be parameterized by the teacher in order to run an economic experiment for teaching purposes (Holt 2002).[2] Further, the Iowa electronic markets[3] (Forsythe, Nelson, Neumann & Wright 1992, Forsythe, Rietz & Ross 1999) and the AuctionBot[4] (Wurman, Wellmann & Walsh 1998) provide an infrastructure for a very specialized set of economic experiments, i.e., trading based on political and economic events and auctions, respectively. An early attempt to provide a more general experiment infrastructure for research purposes is the Vlab at the University of California, Berkeley, that seems to be currently unmaintained.[5] There are numerous psychological online experiment sites on the Internet. As a good starting point the interested reader might visit the (virtual) experimental psychology laboratory.[6]

Section 2 discusses the methodological issue of experimental control in online economic experiments. In Section 3 IT-based solutions that provide maximum control for the experimenter are presented. Finally, Section 4 sketches the design rational of the *Internet experiment infrastructure*, we have developed, and Section 5 draws conclusions.

## 2 Experimental control

This section discusses the methodological issue experimental control with regards to Internet experiments. The discussion relies on methodological findings of online research in experimental psychology that are reviewed in the light of experimental economics.

The control of Internet experiments can be distinguished in three types of questions (Reips 1997): (1) preventing subjects from cheating, (2) con-

[2] `http://www.people.virginia.edu/~cah2k/programs.html`

[3] `http://www.biz.uiowa.edu/iem`

[4] `http://tac.eecs.umich.edu/auction`

[5] `http://elsa.berkeley.edu/vlab`

[6] `http://www.psychologie.unizh.ch/genpsy/Ulf/Lab/WebExpPsyLab.html`

trolling variables in the sense of experimenting in a controllable laboratory, and (3) avoiding confusion. Whereas the latter question is not different from laboratory experiments, the first two questions are of main concern, both to participants and researchers. Table 1 gives an overview on the items a controlled economic experiment via the Internet can satisfy with respect to the control of subjects and the environment.

| Requirements | Internet | laboratory |
|---|---|---|
| Prevent subjects from cheating | | |
| A subject should not play twice | yes | yes |
| Decisions are not made by a group but by individuals | no | yes |
| A subject should not contact former subjects who did the experiment before | partly | partly |
| Controlling variables in the sense of experimenting in a controllable environment | | |
| Only controllable help devices are used | partly | yes |
| Control of subject interaction with GUI | partly | yes |
| Control drop-out of participants | yes | yes |
| Participants should take the recommended time to solve the problem | yes | yes |
| Control quality of the network connection | partly | yes |
| Payment of subjects right after the experiment | no | yes |

*Tab. 1: Satisfiable requirements for controlled experiments*

A major concern related to the Internet technology is to ensure that subjects do not play twice. Internet protocols and Internet services do not provide the feature of unique identification of subjects, so far. We propose the following. For a controlled economic environment the use of a reward medium, usually money, is a self evident percept (Friedman & Sunder 1994). Nearly all electronic payment systems have the built-in feature of identification of payer and payee, a feature that Internet protocols do not provide. By using the identification mechanism of the payment system to identify subjects, the problem of double participation can be solved in an elegant manner.

More difficult to control is that decisions are made by each subject individually and not by groups. In contrast to laboratory environments it is impossible to control if there is more than one person involved in the decision process. Similar to the laboratory environment the problem persists that subjects contact former subjects who did the experiment before.[7] Here, a short

[7]The Internet provides several communication channels, like newsgroups and chat, which

period of time the experiment is available on the Internet provides some help to prevent subject communication. In addition, the recruitment of a heterogeneous subject pool might be advantageous.

Controlling the environment of the subject when conducting an online experiment is our second major concern. The experimenter cannot control whether aids were used to solve the task. Information technology provides the option to offer additional help devices to the subjects, for example a calculator, that can be controlled by the experimenter. A problem related to the WWW is control of subject interaction with the graphical user interface (GUI) of the experiment. The usage of the -BACK- and -FORWARD- buttons of current browsers is out of the experimenters control. Here, IT-based solutions have to be provided to prevent mis-usage of the GUI.

The motivation of subjects seems to be of considerable importance, because subjects might terminate participation at any time of the experiment. Situations, where subjects think they have to explain the interruption to the experimenter are unlikely to happen. The probability of drop-out in the Internet experiment seems higher than in the laboratory experiment (Reips 1997). Therefore, the experimenter should have control over the rate of general drop-out. Especially a selective drop-out should be traced, where subjects leave the experiment with different frequencies depending on experimental conditions (Reips 1997). Similar to this, subjects should take the recommended time to solve the problem.

Can Internet experiments satisfy requirements of experimental economics? Compared to laboratory experiments, the Internet experiment does not provide the experimenter with the same control. Additional noise is added: one source is the use of public networks, another is the lack of control of the subjects' environment, may that be at home or at work.

The Internet experiment seems to be less influenced by systematic errors, however, more random noise is added. Therefore, results produced by the new medium should be applicable in a more general way than laboratory results. This implies, that economic experiments could provide more parallelism to the field by using the benefits of the Internet.

## 3 IT-based solutions to problems identified

This section discusses techniques to solve the issues outlined in the methodological discussion in the previous section. In a first step techniques to increase subject control are discussed and in a second step the focus is on the control over the environment.

might enable participants to meet virtually even though they do not know themselves in person.

## 3.1 Techniques to increase subject control

The main objective with regards to subject control on the Internet is to uniquely identify subjects. Many online systems identify its participants via their e-mail addresses. Since it is not a problem to posses several different e-mail addresses, this is not a feasible approach for Internet experiments with the objective to avoid double participation by the same subject. Demanding very personal information, like social security number, may lead to self selection. A technique based on identification number or a social security number might not be effective, as there is no way to check whether a given number belongs to the participant.[8] Demanding very personal information from subjects may lead to self selection. For similar reasons do experiments conducted with a lottery-based reward ask for payment information only after the subject has been identified to win. In this case double-participation can only be determined at this (too) late stage.

To reduce the potential that one subject performs the same experiment under several different identities, payment information is used in addition to the e-mail address to uniquely identify each subject. While this reduces the number of potential double participants, it does not fully prevent such abuse. So far we use a traditional payment system, transfers to checking accounts, to identify subjects.

Currently we evaluate the integration of electronic payment systems in order to provide payments right after the experiment. For the above mentioned reasons, it is particularly important that the payment-system uniquely identifies the recipient of a transaction for Internet experiments.[9] In addition, the electronic payment mechanisms must operate timely and credit the necessary funds in a predictable manner. Still many electronic payment systems have been developed for different target applications in mind. Several systems provide extensive anonymity to the participants of a transaction and have properties similar to cash, e.g. DigiCash. These kind of systems do not provide the authentication needed for online economic experiments. Other systems, most notably credit card transactions via Internet, mainly specialized in customers paying their purchases. With regards to online experiments the option of peer-to-peer payments seem to be important, especially transfers from the experimenter to the subjects are necessary. Lately Paypal started to provide a successful peer-to-peer payment service that is widely used for online auction

[8] At least in Germany it is feasible to compute whether the personal identification number presented is a valid one since the algorithm is public.

[9] Subjects might not open up a new account exclusively for participation in the experiment since costs might outweigh the expected gains. One argument which threatens unique identification is the use of several payment accounts by a participant. In this case the experimenter can check for the same name.

payments. A good starting point on the evaluation of electronic payment systems can be found in MacKie-Mason & White (1997) and Schmidt & Müller (1999).

A Web based technique to augment subject identification is the use of "cookies". The cookie is an identifier that is stored on the users' client browser. Subjects are able to prevent their browser to accept cookies, they can remove them, or simply use a different web browser/computer. Therefore, a cookie is not a unique identifier of a subject. However, most Internet users are not familiar with these issues, so that this method can at least increase control.

The issue of whether or not a specific subject has fully independently performed an experiment cannot be avoided, since the experimenter has no control over the physical environment in which the subject is performing. The issue of one subject contacting another former subject to intentionally or accidentally pass on influential information can hardly be avoided for any experiment and only supported by organizational solutions like short availability of the experiment. Moreover, the chances of subjects actually knowing each other in a very diverse subject pool can be reduced by very selectively choosing among the user base of registered users, e.g., only notify one user per identifiable domain (company, department etc.). This is supported by presenting subjects individualized URLs, this means an identifier is added to the URL of the experiment site in order to make sure that only the invited subjects participate.

To cope with the issue of no-shows and subject's exact appearance, we are currently working on a reputation mechanism. In our system the subjects are rated with regards to their in time participation in former experiments. The experimenter can invite subjects on the basis of an index that distinguishes between positive and negative ratings.

## *3.2 Techniques to increase control over environment*

There are several objectives with regards to control over the subjects' environment during the experiment. One demand of economic experiments is that only controllable help devices should be available. This includes the use of aids and tools, especially calculators. In case of Internet experiments only the use of provided aids can be controlled. Therefore, it seems important to integrate easy to use tools, like calculators, in the experiment to provide more control over the individual usage of helpers.

A further topic is to avoid and record drop-outs during the experiment. Most important is to distinguish between active and passive drop out. A passive drop out occurs due to a broken network connection or a crashed client computer. An active drop out occurs due to a user giving up. For either case it is easy to record the fact that for a specific user ID an experiment was not completed. Different options are available to handle this case. An experimentee may be given additional chances to complete the experiment on future logons, or maybe denied participation in the future.

It is more difficult to distinguish between both kinds of drop outs. To avoid active drop-out one needs to identify experimental stages with high drop-out rates and experiment with means to keep users' attention. Monetary rewards have to be calibrated in order to give subjects the right incentives not to drop out.

Participants should take the recommended time to solve the problem. We use several techniques to record time. Most important, the time is recorded at the beginning and the end of the experiment. In case economic decision variables are recorded in the database the time will be added as well. The interaction with the user-interface can be monitored by a standard log file of a web-server in case of a HTML based user interface. The only problem is to identify individual sessions when two different user use the same IP-address and browser.[10] Therefore, we propose a custom `access_log` which also includes the session-ID, the login of the user, and the experiment identifier.[11] The logfile is shown in Figure 1.

```
pD9E2695B.dip.t-dialin.net - - [21/Mar/2002:10:25:32 00100] "GET
/254551037374317/Welcome.mhtml HTTP/1.0" 200 5695

pD9E2695B.dip.t-dialin.net - - [21/Mar/2002:10:25:32 00100] "GET
/254551037374317/Welcome.mhtml HTTP/1.0" 200 5695
254551037374317 testuser AC
```

*Fig. 1: Standard access_log top, custom access_log bottom*

This custom logfile allows to compare actual and expected time to work over the whole and specific parts of the experiment of an individual subject identified by a username and a cookie based session-ID. And it provides a means of control of subject interaction with the GUI, i.e., which pages are requested.

A key design question for the implementation of the online experiment is the distribution of functionality to the server, to the client, or to both. It goes without saying that the implementation metaphor used must support this decision, i.e., pure HTML must be supported by server–side processing (e.g., JSP, PHP, or MetaHtml), Java-Script can realize client–side processing, and Java implements a hybrid approach. However, the more experiment functionality is "out sourced" from the server to the client, the higher the risk of potential

[10] This might be the case when two participants are connected to the experiment via the same proxy server.

[11] This function is actually implemented as a server side-include that writes the information including browser identification and referrer in a database. For a straight forward presentation the standard `access_log` file format is used in the figure.

fraudulent user interactions. The infrastructure provider has little control over the client side processing to prevent illegitimate use. On the other hand, data input integrity checks on the client side may substantially benefit the overall processing, since less browser–server interactions result, due to pre–validated input data (i.e., input errors are signaled to the user right away without a server connect).

Our experience in deploying economic experiments via the Internet has shown that some participants do — intentionally or unintentionally — try to "break" the system, e.g., through false input and aimless browser button use. This is a severe problem, since the experiment implementer has very little control over the way a participant uses the browser.

The solution we used for a previous experiment (Anderhub et al. 2001) is a client side approach by JAVA-applets and database connectivity classes (pre–JDBC) for the communication with the database. When using the client side approach, keeping state on the client is an easy task. In our case the database connectivity was implemented on the client, therefore some subjects could not participate because of policy restriction (e.g., proxy server and firewalls) of their local site connecting to the Internet. This problem can be eliminated by implementing a middle–tier, that handles the connection to the database, and communicates with the applet by standard http–protocol.

The server side approach to implement experiments uses (plain) HTML over the standard http–protocol; yet, it is more complex to keep track of the users' state. The technique we use in the current infrastructure is based on a finite state machine representation of the experimental stages. A stage constitutes a unit of interaction between the experimenter and the participant. This may include experiment instructions, decision forms, and questionnaires. Commonly an experimental stage corresponds to one page delivered to the user's browser (see Figure 2).

In this scheme one central file implements the finite state machine. It assembles the page transferred to the client browser dynamically according to current state and user action. This has two major advantages. One, the server maintains all state information and releases the right information (according to the experiment design) to the user. Two, a single URL is associated with this central control file, i.e., a user cannot jeopardize the operation of the experiment through intentional manipulation of the current URL (e.g., by guessing URLs).

Experimental stages are represented by states, and all possible user actions represent state transitions. A user action, for instance, is the pressing of a form–submit button, but also the forward or backward browsing through the experiment instructions. We implement all actions via form buttons, except for actions performed by the user with her browser (e.g., a page re–load). These latter actions constitute an issue, since at the server–side it may not al-

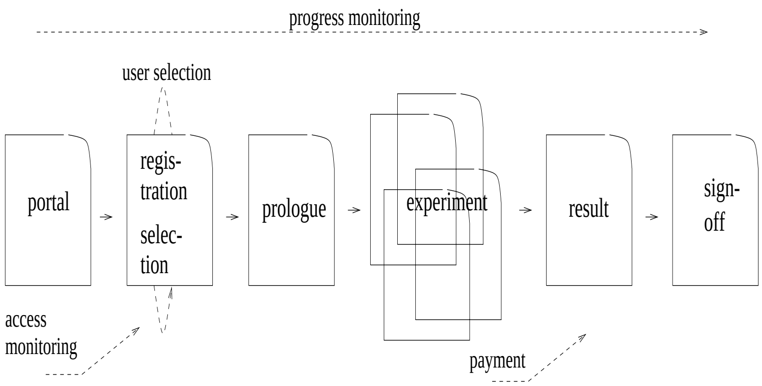


*Fig. 2: Experimental stages*

ways be possible to "catch" these actions (e.g., a back–button action might access the client browser page–cache only). We influence this by setting cache invalidate flags, so that a page that should not be re-loadable from the cache will be fetched from the server by the browser upon the occurrence of the re-load action. However, this requires the correct implementation of this protocol by the browser used.

To reduce the subject–browser interaction to the allowed actions, one can use the following approach. First, the experiment will open in a separate window by using JavaScript. Thus, JavaScript has to be enabled in order to participate. The experiment window does only contain the delivered HTML page, all buttons, address windows, title, and status bars are disabled. Second, in the experiment window the user is prevented from accessing the context-menu via the right mouse button by using the now surely enabled JavaScript again. At least, this is possible for the most used browsers Internet Explorer and Netscape Navigator. Thus, the only interaction a user can do with the experiment is either to use the provided buttons and links on the experiment page or to close the window and drop out. Although this method is not 100% safe, it increases control over the subject's browser interaction. Sample code is provided on our Web page.[12]

## 4 Infrastructure architecture and components

In this section we provide an overview of the design of the experiment infrastructure we have built to perform economic experiments on the World Wide

[12] `http://experiment.mpiew-jena.mpg.de/virtlab`

Web. Ultimately, we aim at offering an Internet service for use by the research community to perform and to participate in online economic experiments. This service offers a set of functions commonly needed by the experimenter, such as accounting, user authorization, and registration. Furthermore, our approach is to provide an environment that automates many tasks that have to be performed by the experimenter, such as participant selection and payment.

The infrastructure aims at providing maximal control over the experiment and its subjects to cope with the issues outlined in the previous sections. Figure 3 depicts the individual components of the environment described in more detail below.

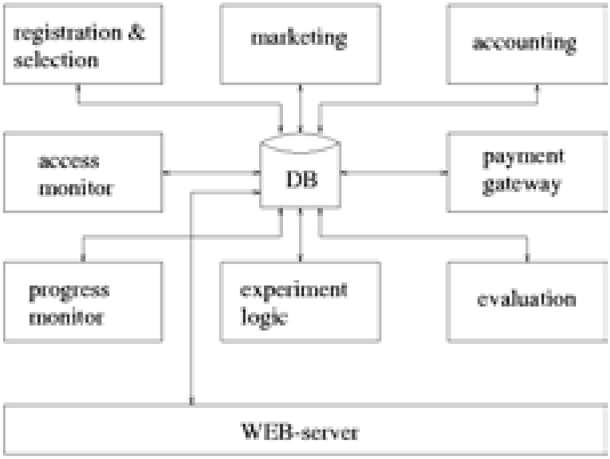


*Fig. 3: Architecture of the experiment infrastructure.*

The *registration* and *selection component* performs user registration and makes user selection decisions. Registration is a simple dialog asking the user to enter name, e-mail, banking account number, and other information. To ensure a certain degree of integrity of the entered data we interact with the user by sending her an access code by e-mail. The e-mail is generic not revealing the experiment's URL. A user must enter her identification and access code to actually sign–on for the experiment. With this procedure we want to ensure the presence of a valid communication channel with the subject.

User selection is done while registration is in progress. It is based on a set of rules granting or denying access for a user. Part of the rules derive from the particular needs of the experiment provider, who wants to address mostly students, or only females, for instance. Other rules are generic and directly address the experiment integrity, i.e., ensure that a novel subject is performing the experiment, for example. Note, that both kind of rules can only approximate the imposed constraints, and true integrity cannot be guaranteed in both cases. We think it is therefore best not to reveal the involved rules at this point.

The *access monitor* records access time, IP–address of client, system and browser type of client, and other information. The collected information is used by the selection sub–system, for instance, to derive access decision. The information is also used by the marketing component, to measure marketing efficiency and direct further advertising efforts.

The *progress monitor* records similar information during the entire experiment and ensures that parameters returned to the client are appropriately set (e.g., cache–reload attributes). We use a set of techniques to monitor the progression of the subject in the experiment. An analysis of this information may reveal that a subject went multiple times over the experimental instructions while being asked for decision values.[13] This information may be helpful in evaluating the individual results.

The *accounting monitor* component manages the financial assets for the experiment and communicates about payments with the *payment gateway*, the interface to the banking system connected. Our design aims at maximizing security and control over the financial assets available. At each moment in time the component knows exactly how much money is still available. If a critical limit is reached or an unusual high amount is being transferred an administrator is immediately notified and the experiment is halted. Default thresholds are defined and may be configured for each new experiment.

The *payment gateway* is the interface to the banking mechanism used. We aim at supporting several mechanisms: manual banking, online banking, and electronic payment systems, as they become available. The ultimate goal is to provide a fully automated payment system integration.

The key problem we are facing is the incapability to perform peer–to–peer payments via credit cards, the primary means of payment on the Internet to date. Unlike most electronic commerce transactions, the economic experiments we are targeting do require that the Internet service (the experimenter) pays the customer (the subject). Only recently banks seem to offer an online API (in Germany the standard HCBI is emerging) to effectuate customer transactions automatically. Until now, online banks offer their services through an HTML–based form, or Java–applet targeted at the *human user*. The lack of a standardized online banking API renders program–driven payment transactions very difficult.

The *experiment logic interface component* constitutes a set of interfaces that permits to plug in experiment implementations. The interface is open, and any implementation compliant to the interfaces may be *plugged in*. Tech-

[13] In case the experimental design foresees such actions.

niques for the management of methods in the Internet environment, which have been developed within the context of the MMM project (Jacobsen, Günther & Riessen 2000), are used to realize this component.

The *evaluation component* serves as direct interface to a statistics packages and to perform result evaluation "on–the–fly". This can be useful for standardized questionnaires provided by the experimental service. For specific experimental data the experimenter must identify how results are aggregated and evaluated, further processing of the results may then be carried out automatically. This evaluation is only a rough estimate and preliminary step, since outliers in the data are difficult to recognize automatically. We are currently working out details of this component, such as online vs. off-line processing and integration in the overall experiment infrastructure.

The *marketing* and recruitment component serves to advertise the experiment before and possibly during the experiment. It draws upon a large database of e-mail lists, individual e-mail addresses, newsgroups, and free Internet–ad space providers. The data inherent to this component is highly domain dependent, and will have to be carefully collected for alternate use. The component automates the sending of e-mail announcements to lists, the posting in news–groups, and the advertising of the experiment on free Internet–ad sites. The component also automates the return traffic processing as much as possible, e.g., management of bounced e-mails. The experimenter states in a graphical query what kind of subjects she wants to address: students or general public, specific sex, and/or geographical origin. At the end the experimenter states how many subjects should participate. Finally, the query draws the specified number of subjects randomly out of the eligible ones. In the future we aim at further developing the functionality of this component by also incorporating paid–ad providers and means to analyze feedback.

The *sign-off* component is a very simple component that manages mailing and interest lists. It prompts the user and, if she is interested, signs her up for different mailing lists concerning distribution of research reports about the experiment and further experimental economics research.

The implementation of the experiment infrastructure is based on Meta–HTML (Fox 1998), a server–side include programming environment that enables to establish and maintain session state, to manipulate databases out of HTML–documents, and to author dynamic HTML–pages, among others. The components are built around a database that maintains all experiment and participant data.[14] The Virtual Laboratory is online[15] and currently draws on a mailing list of more than 1,000 former participants.

[14]The infrastructure is build around open source software components: Meta-HTML Web server and scripting language, MySQL database.

[15]`http://experiment.mpiew-jena.mpg.de`

# 5 Conclusion

Internet experiments have become a popular tool for several research disciplines, such as experimental economics and experimental psychology. We have outlined several methodological constraints that govern Internet experiments as opposed to computer–based laboratory experiments. One of the major restrictions is the lack of control over the participant. We have motivated the design of an experiment infrastructure that aims at providing an improved degree of control and an automated management of many experiment tasks to the experimenter. The infrastructure we are developing constitutes a generic system with functional entities used in most e–commerce systems. These components comprise access monitoring, progress monitoring, marketing, user authorization and registration, and payment system integration. Furthermore these components may be used for online polling and market surveys, alike. In the future we aim at offering these infrastructure services to the research community to perform online experiments.

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