Abstract

Presence research relies heavily on empirical experiments involving subjects in mediated environments. Since presence is a complex, multidimensional concept, experiments on presence can be extremely resource intensive and produce large amounts of data of different types. As the presence community matures, we would like to suggest that data collected in experiments be made publicly available to the community. This will allow the verification of experimental results, comparison of results of experiments carried out in different laboratories, and evaluation of new data-analysis methods. This will, eventually, lead to consistency in approaches and increased confidence in results. In this paper we present the complete dataset from a large-scale experiment that we have carried out in highly immersive virtual reality. We describe the data we have gathered and give examples of the types of analysis that can be made based on that data.

1 Introduction

We regard presence as a successful substitution of real sensory data by artificially generated sensory data. By a successful substitution we mean that the participant acts upon these artificially generated stimuli as if they came from the real world. By acting, we mean that we expect the participant’s response to be similar to the response in the real world on many levels, ranging from unconscious automatic responses through deliberate volitional behavior, up to the subjective feeling of being there. Thus, we believe that presence should be studied on multiple levels, using multiple types of data.

Many studies on presence are being carried out, and we suggest that as a community, it would be advantagous to start to standardize our experiments and methodology. To some extent this has started already, with the development of reusable questionnaires (Witmer & Singer, 1998; Slater & Steed, 2000; Lessiter, Freeman, Keogh, & Davidoff, 2001; Schubert, Friedmann, & Regenbrecht, 2001) and open source platforms on which experiments can be developed (e.g., VRjuggler; Bierbaum et al., 2001). However as we noted above, presence is a complex phenomenon and there are many types of data being generated. Some of these data sources, such as physiological monitoring, are quite complex and difficult to analyze, others such as event logs are very specific to the experiment. Overall we are dealing with very rich and diverse data and thus it would be useful to have some degree of standardization in data collection and data analysis. This will serve the following four goals.
Researchers can test new methods of analysis without carrying out time-consuming experiments.
Researchers who have experiments with huge amounts of data could expect several groups to tackle different aspects of the analysis.
It would promote progress in presence methodology, by allowing a comparison of methodologies and research techniques.
It would make possible the comparison of results among different experiments, and even among experiments carried out in different laboratories.

Standard datasets are common in other fields. For example, in medical imaging, standard datasets are an important benchmark against which to test novel algorithms. A well known example is the Visible Human Project, a project of the U.S. National Library of Medicine, which has recently made digitized datasets of male and female human cadavers available for research and education. Other fields such as astronomy and genetics make strong use of shared datasets; and fields such as these have been one of the main drivers behind recent interest in Grid computing, specifically the sharing and indexing of very large datasets (Foster & Kesselman, 2003).

When it comes to human task performance, large datasets such as these have not been so useful, mainly because of the variety of behaviors that are expected. The trend has been to attempt to standardize specific small tasks that characterize the likely performance of a range of aggregate tasks. From the HCI field, one good example is the very simple task of using a control to move an object on a display from a start location to a target box (e.g., simulating hitting a button with a mouse cursor). The performance of this has been well characterized by the use of Fitt’s law (MacKenzie & Buxton, 1992). Closer to the VE field, both Bowman, Johnson, and Hodges (1999) and Poupyrev, Weghorst, Billinghurst, and Ichikawa (1997) have proposed a testbed of 3D user interaction tasks.

In this paper we present the complete data for an experiment we have carried out in a Cave-like system. (We use the term Cave to describe the generic type of system as described in Cruz-Neira, Sandin, & DeFanti, 1993.) We hope this will encourage other researchers in the field, and will gradually result in a large corpus of data available to researchers in the ways suggested in this paper.

The experiment was large-scale including several types of measurements, both quantitative data such as physiological measurements and qualitative data based on semi-structured interviews. The hypothesis and the results for this specific experiment are not the focus here. We describe the data itself and point to the analysis techniques we have used. We suggest other techniques to analyze the same data, and some other types of data that may be used in the future.

Analyzing large amounts of logged data is, of course, not unique to presence research—it plays a role in VR, mixed reality, and in human-computer interaction research in general. Perhaps in presence research, more than in other areas, we are hoping that the integration of multiple measurements would ultimately allow us to reconstruct the subjective experience of the subject, rather than just observe external behavior.

The data for the experiment, as described in this paper, can be downloaded from www.presencedata.info/. The data is organized in online tables, and details are provided. In the paper below we refer to the data by mentioning the online table number; these can be accessed from the main URL number; these can be accessed from the main URL number above. The experiment is described in this issue (Slater et al., 2006).

2 The Data Sources and their Independent Analysis

Analysis methods are typically classified into quantitative and qualitative methods. We do not disagree with this distinction, but in this paper we find it useful to make another distinction: between data that is temporal and data that is not.

2.1 Temporal Data

It has been argued that rather than being a stable constant throughout the mediated experience, presence
may vary over time (Biocca, Burgoon, Harms, & Stoner, 2001; Ijsselsteijn, Freeman, & de Ridder, 2001; Sheridan, 1992). Generally, we would like to be able to measure how presence varies over the duration of the experience, and how it is affected by specific events in the environment, and across a range of responses. In particular, we encourage the inclusion of physiological data in the study of presence. One of the first studies to show that presence can be studied as an objective, measurable response, based on galvanic skin response (GSR) and heart rate, was carried out by Meehan, Insko, Whittington, and Brooks (2002).

Ideally, all data could be placed on the same timeline, and visualized together. In this section we present these types of data independently, and in later sections we discuss possible ways to cross-analyze them.

Most of the temporal data is generated digitally and the main challenge is synchronization. Accurate synchronization is critical for event-related responses and is discussed in Section 3.1. We make significant use of the Virtual Reality Peripheral Network (VRPN)1 to synchronize among the data and the VR system. VRPN is an open software platform that is designed to implement a network-transparent interface between application programs and the set of physical devices (trackers, etc.) used in a VR system. Using VRPN, all data generated during an experiment can be synchronized, sent over a network, and stored with uniform timestamps for later analysis.

2.1.1 VE Events. Events and actions carried out by the system can be easily logged by the application. In our experiment we recorded all the instances in which the virtual characters spoke. The data is included in online Table 1A. It may be useful to record the position of characters and objects during the session and their positions are provided in online Table 1A. The gaze directions of the characters were not recorded in this experiment, although this information may be useful in social scenarios.

Events carried out by the participant typically involve


a tracked interaction device. In our experiment, we have allowed, in one condition, for subjects to indicate breaks in presence (BIPs), using a wireless mouse device. The data is included in online Table 1B. Typically, VEs would allow interactions of subjects with the VE and such events would similarly be tracked and logged. We did not record when participants speak, but this could be done. The analysis of this type of data is typically useful for detecting event-related physiological responses. For example, one can look at the physiological state of the participant whenever something happened in the VE; examples are given in Section 3.1.

2.1.2 Tracker Data. In VR the participants are typically head tracked. This provides extremely useful information about their position and head direction at any moment. We expect this gives us a good approximation of what they were looking at, without the need to perform eye tracking, which is difficult in a Cave environment.

The tracker data from our experiment is included in online Table 2. Examples of typical analysis of this kind of data are spatial analysis (see Section 3.3) and event-related analysis (see Section 3.2). We did not use head-tracker data to reconstruct what the subjects were looking at; this should be possible since the trackers include orientation information as well as position.

2.1.3 Galvanic Skin Response. GSR, also called galvanic skin conductivity or electrodermal activity (EDA), is measured by passing a small current through a pair of electrodes placed on the surface of the skin and measuring the conductivity level. In our experiment GSR was sampled at 32 Hz, and the signal was obtained from electrodes on the middle and index fingers.

The GSR data for the two experimental conditions appears in online Tables 3A and 3D. More details about GSR, and about analyzing GSR data from this experiment, can be found in Slater et al. (2006) in this issue.

2.1.4 Electrocardiograph (ECG). An ECG records the electrical activity in the heart. The main parameter extracted from the ECG is the heart rate. In
addition, the heart rate variability (HRV) can be used to
describe the physiological behavior of the participant,
and an event-related heart rate response may be useful
to study the reaction of the subject to an event (e.g.,
such as a BIP).

The ECG data for the two experimental conditions is
provided in online Tables 3B and 3E. The sampling rate
is 256 Hz. Slater et al. (2006) provide an analysis of the
ECG, including a comparison of the training and exper-
imental phases, comparison of social phobic and non-
social phobic participants, and event-related ECG.

2.1.5 Respiration. The respiration signal mea-
sures the inhalation and exhalation phases of the human
subject. The signal can be used to extract the deepness
and frequency of the respiration. Therefore it is neces-
sary to low-pass filter the signal to remove noise compo-
ents and movement artifacts. Then each zero crossing
of the bipolar respiration signal is detected in order to
calculate the frequency. Event-related respiration
changes around a BIP can be investigated. For example,
it is possible to find a changed deepness and frequency
after the BIP. One hypothesis that is possible to test
with this data is that generally subjects hold their breath
for a brief period after the BIP occurs.

The respiration also modulates the ECG signal with a
frequency of about 0.1–0.2 Hz. This modulation effect
should be considered when the ECG is analyzed; details
can be found in Florian et al. (Florian, Stancak, &
Pfurtscheller, 1998). The respiration data for the two
experimental conditions appear in online Tables 3C and
3F.

2.1.6 Video. The whole experiment session was
videotaped for all subjects. In our experiment we used a
Cave-like system (specifically a Trimension ReaCTor)
where the projection takes place on three walls and on
the floor. The video camera was placed outside the Cave
so that it captures the whole area. This is useful to ob-
serve the subject’s motion throughout the physical
space of the Cave, and also allows the analysis of their
main body gestures and postures. However, the subject
is typically shown from the back. Generally it would be
difficult to pick up the subject’s facial expressions, given
the relative darkness in the Cave and the fact that sub-
jects wear VR goggles. We still recommend placing an-
other camera that picks up the subject from the front;
for example, in our Cave setting, we could eventually
place one on the top of the front Cave screen.

The video can be used for testing hypotheses, for pro-
viding information about the experiment to researchers
who were not present, and for later analysis of body lan-
guage.

2.1.7 Video Interview. Following the experi-
ment, the subject watched the video together with the
experimenter and reflected on his or her experience. We
have used this video interview to gain some insight for
later exploration during the post-experiment interview
(Section 2.2.4). Ideally, this interview by itself should
be recorded and provided with the data, because it pro-
vides a potentially insightful glance into the subject’s
experience when it is still fresh, and in a way that allows
the subjective impressions to be temporally aligned with
the experience.

2.1.8 Additional Measurements. In the future
we hope to explore additional types of temporal data.
Some experiments involve conversation, either among
multiple subjects in a multi-user experiment or between
a subject and a confederate. Recording such conversa-
tion and synchronizing it with the other types of data
can be extremely useful.

Other types of physiological data can also be used.
Our system now includes an electroencephalograph
(EEG) measurement as well. This has been used for a
brain-computer interface for controlling the Cave
(Friedman et al., 2006), but may also be used for post-
experiment analysis. Similarly, it should be possible to
analyze muscle activation in the form of electromyo-
gram (EMG) recordings.

It is also possible to track body parts in addition to
the head. However, the bar room environment was ap-
proximately the same size as the physical Cave so that
subjects could move around by actually walking rather
than use the Wand tracking device. This was a deliberate
design decision for the experiment in order to avoid
subjects having to learn to use the Wand, so that their
main focus would be on interaction with the virtual characters. Therefore, hand-tracking data for this experiment is not available. For some experiments it may be useful to include such tracking data since it is possible to partially reconstruct hand and arm gestures from such data. Naturally, full-body tracking is highly useful for experiments that may involve body language and non-verbal communication. If such tracking devices are not available, it would still be possible to utilize experts in body language who can observe the subjects and interpret their behavior; this can be done after the experiment by watching the video. Changes in posture have been used before in presence experiments (Freeman, Avons, Pearson, & IJsselsteijn, 2000).

In addition to documenting the experiment sessions by video, it would be useful to be able to record the complete interaction session within the VE as a log file that can be played back by the system software. Such recording of interactive environments, although not a new idea, is still not straightforward and is not provided by any of the standard VR toolkits. This means that researchers need to spend time modifying software to support record and replay functionality.

Some researchers have experimented with such capabilities (e.g., Hart, 1993; Greenhalgh, Flintham, Purbrick, & Benford, 2001). Although such logs are usually for the purpose of debugging or creation of other types of media representation, Steed et al. (Steed, Vinayagamoorthy, & Brogni, 2005) used such a system in an experimental process. They describe a system that records a Dive session and allows the experimenter to play it back within Dive and experience it as a first person or third person view. It is also possible to use intelligent tools that create summaries from interaction sessions. An example is a tool to create movies that review the interaction from various angles, and allows focusing on specific events within a session (Friedman, Feldman, Shamir, & Dagan, 2004).

2.2 Nontemporal Data

In this section we discuss data that is collected after the experiment, and thus cannot be temporally aligned with data collected during the experiment.

2.2.1 Questionnaires. It has been pointed out several times that questionnaires are problematic in the context of measuring presence—see the discussion in Slater (2004). Questionnaires may be made more useful and reliable if their results are integrated with qualitative results and with physiological data.

In addition to presence questionnaires, it is often appropriate to administer psychological tests, such as personality tests. Such tests may provide important explanatory variables for a particular experiment, or may assist with cross-experiment comparisons. As an example, in the experiment described here correlation was found between a score on a social phobia questionnaire and ECG. The results for the psychological test that assesses the degree of social phobia (Watson & Friend, 1969) are given in online Table 5.

Each participant in our experiment completed a questionnaire prior to their immersion that gathered basic demographic information, and background information regarding their use of computer games. The information is included in online Table 5A.

The bar experiment included two conditions. In the main condition, which included 20 participants, no questionnaires were administered. In a second condition, with 10 participants, the participants were instructed to click a wireless mouse whenever they experienced a “transition to real” (a BIP). In that second condition the subjects completed questionnaires; the results are available in online Table 5.

3.2.2 Immediate Question. Immediately after the experience, and before taking off the equipment or leaving the Cave, participants were asked to answer two questions concerning their immediate impressions regarding their overall sense of being in and responding to the bar.

The purpose of these two questions was to capture participants’ immediate subjective response to the expe-
experience in a way that was as far as possible unclouded by post hoc rationalizations. Afterwards, they were able to expand on their answers in the semi-structured interviews. The responses to the immediate questions are given in online Table 6C.

3.2.3 Presence Graph. During the interview, participants were asked to draw a graph describing the extent to which they felt they were in the bar versus the laboratory throughout the experience. A sample graph is shown in Figure 1.

This was an attempt to bridge the gap between temporal and nontemporal data. While the diagrams provide some temporal information, they cannot be aligned with the temporal data, and thus are not considered here to be temporal. Ideally, they could serve as a link between the interview and the temporal data. For example, while drawing the diagram, the subject can point to certain extreme points in their presence function and describe how they relate to their responses during their interview. The presence graphs were abstracted and classified into four types (Garau et al., 2004); the data is provided in online Table 6C.

3.2.4 Post-Experiment Interview. The post-experiment interview is vital for understanding the statistical data in a deep way, beyond what questionnaires can reveal, and can additionally provide hypotheses for future research. Such interviews typically contain a lot of fascinating insights that are often unexploited because, due to their subjective nature, they are difficult to analyze in a rigorous manner. However, one possibility is the use of Grounded Theory, which was used by Garau (2003) and by Thomsen (2004) for analyzing interviews in the context of presence research. By including the interview transcriptions with the data we hope other researchers can get an insight into the subject’s experience, and perhaps suggest methods of analyzing this data in a systematic way.

In our experiment each interview was conducted using a semi-structured interview agenda, to ensure that it did not stray from the research questions in which we were interested. The interviews were taped and then transcribed verbatim. Garau et al. (2004) discuss the interview techniques and the results obtained for this experiment. The transcripts for the two experimental conditions are included in online Tables 6A and 6B.

3 Compound Analysis

In the previous sections we described the individual data types and the analysis we have carried out based on single data sources. In this section we describe analysis of two or more elements together. Again, the intention here is to explain what types of analysis are possible, rather than to focus on specific results from this experiment.

3.1 Event Related Analysis

It was of great interest to see if we could detect measurable responses to events in the experience. Our experiment was specifically designed to find out if we could detect a physiological signature to BIPs and physiological responses to other events such as when the virtual characters spoke.

Another possibility that we are examining is whether the stiffening stabilizing reaction that subjects have to an anomaly in the VE is detectable as a loss in height that can be seen in the head tracker data. In the future we could combine this with EMG data from the soleus muscle in the lower leg to detect when a subject is experiencing a BIP.

An example of one subject’s height following a BIP
appears in Figure 2. The subject is reduced in height by nearly two centimeters after the BIP. Due to high variance in most peoples’ standing height, our results in this direction are so far inconclusive. However, given that many emotions, such as stress, are manifested as muscular tension in the body, looking at the results of this muscular activity whether through EMG or postural change is a promising method to analyze a response to VR.

3.2 Spatial Analysis

A spatial representation of time-variant signals is a very useful tool for the experimenter. A quick glance may allow detection of areas of the VE where the signal has extreme values, and this may provide clues for further analysis.

Specifically, an interesting approach in the data analysis is through linking the physiological values with the position of the subject in the virtual space. The resulting graph shows how the signal spatially changes over the VE and it can be useful to detect whether there is a difference in the way different areas affect the subjects’ physiological responses.

While such plots may not alone qualify as conclusive evidence, they could be a useful starting point for further analysis of physiological responses and proximity to virtual characters. Figure 3 illustrates this point for some subjects in the bar experiment: Figures 3a and 3b show subjects who had stronger GSR values next to the barkeeper whereas Figures 3c and 3d show subjects with the opposite trend. Of course, many subjects did not show a clear pattern at all.

This technique is typically more useful when the VE is large, and the exploration of the VE is of interest in itself. In the case of the bar experiment, the room was spatially limited by the Cave’s walls, and movement was restricted.

Interestingly, the qualitative analysis of the interviews seemed to reveal that the subjects responded differently to different areas in the virtual space, as related to the spatial organization and to the virtual characters (Garau et al., 2004). It would be interesting to compare this qualitative evidence with the objective physiological measure. Our tracker data definitely seems to indicate that subjects spent more time on the side of the barkeeper (barman in British English) than in the other side of the bar.

3.3 Merging Temporal and Nontemporal Data

Subjective post-experiment descriptions of the experience can be insightful; examples from the experiment discussed here appear in Garau et al. (2004). However, how do we associate these with temporal data? We would like to have an equivalent of the interview, which is obtained during the experiment.

One such option may be to ask the subject to verbalize their subjective experience out loud, during the experience, and such a think aloud technique is discussed in van Someren, Barnard, and Sandberg (1994).

Another option is possible if the VE scenario includes a well-defined narrative. If so, subjects can be encouraged, in the interview, to describe their feelings as related to certain events. For example, in a modified bar experiment, subjects could be encouraged to describe their feelings when a character tells them something intimate. Even though a few minutes pass from the time of the real experience to the time of the reconstruction, the information gathered in this way may be useful. Such recollection of the experience may be done during the video interview, as mentioned in Section 2.1.7, or with a replay of the VE events as suggested in Section 2.1.8.
3.4 Inter-Experiment Comparisons

Ideally, it should be possible to compare experiments carried out by different researchers in different laboratories, even if only part of the data overlaps. One of the problems may be that different researchers have different underlying theoretical and methodological approaches to presence. This results in substantial differences among experimental designs and data collection. Our view is that such differences are a reflection of the fact that presence research is still a very young area. In fact, by sharing data among researchers, in the manner suggested in this paper, we hope to provide a more concrete context for the presence research community to discuss such issues.

4 Towards Standardization of Presence Data

In this section we provide some initial recommendations for such a future standard, based on the experience we have gathered in the experiment reported here.

4.1 Time

All temporal data items need to be synchronized with timestamps. It is important that all logs be recorded with enough timestamping data so that log files from different sources can be synchronized post hoc. Because of clock drift and time interruptions we recommend including absolute timestamps even for
physiological data that are recorded with high frequencies. For example, if the ECG is recorded at 256 Hz, each of the 256 samples should include a pair of values: the timestamp and the recorded ECG value. We recommend using the complete time for each timestamp, including day, month, and year. This would make it easy, for example, to detect whether two chunks of data belong to the same experiment session or not. The only disadvantage of keeping such detailed time logging is file size and storage space, but this is typically not a problem with contemporary hardware and software systems. The IEEE standard for time series, or IEEE 1858 Precision Time Protocol (PTP), may be a considered a candidate.

Aside from timestamping rigorously, care must be taken to make sure that clocks are synchronized between machines or that a correspondence between the times can be made. The usual way to do this is to have a “clapper-board-signal,” a signal that can be identified in all log files. If this is not possible (or in addition), the clocks themselves can be synchronized. In increasing order of accuracy, this can be done manually, by a network time protocol, or by installation of an external radio clock.

### 4.2 Space

Many of the data items collected in experiments have a spatial component. There will be a need to standardize coordinate systems and metrics for both virtual and real space data. Such position data might have various degrees of accuracy. Collecting, logging, and analyzing position data is a main research area in mixed and augmented reality (Newman et al., 2004), and their conclusions should feed into any standard adopted.

### 4.3 Events

Actions performed by the subject or by the system need to be logged in with accurate timestamps. Due to the large variability in scenarios and applications studied in presence research, it would be difficult to come up with a standard at a low level of granularity. A simple, initial approach might be to use a tuple structure, where each event is a tuple \((\text{actor}, \text{action}, \text{parameter})\), and the legal parameters are derived from the action.

### 4.4 Software Tools

Assuming a corpus of data gradually becomes available, we expect it would be useful to share tools for data recording, collection, and analysis. We have used one such tool that is already available and used by several labs: VRPN (discussed in Section 2.1); this is a combination of a networking protocol and open software that implements the protocol.

### 4.5 Media Resources

We also recommend sharing media resources, specifically 3D environments. This is necessary to allow replication of experiments by other labs. Exchanging static 3D models is possible since there are some formats that can be imported and exported from most software tools, such as VRML\(^3\), and Collada\(^4\) is a specific project aimed at open exchange of digital assets.

Unfortunately, it is much more complicated to share interactive applications. Even if researchers are willing to share their software, including the source code, for use by the community, it is often time consuming to port an application to different hardware and software platforms. This is a major problem for VR and mixed reality, faced by both industry and the research community alike. Open source platform software such as VRJuggler and Diverse are promising avenues of research. For example, although on selection techniques, not presence experiments, Steed and Parker (2005) have made the complete VRJuggler-based source code and data files needed to run their experiments available online.

### 5 Discussion

In this paper we detail the types of data that we collected during one experiment, and the techniques we

used to analyze this data. There is still a long way to set standards for data sharing and analysis in the presence community.

Two main ethical considerations come to mind. The first concerns data usage and the need to maintain the privacy of subjects. In our experiments subjects sign a consent form, and they are free to withdraw from the experiment at any moment. The experiments are agreed well in advance by an institutional Ethics Committee. We suggest mentioning the fact that the data may be made available to a shared pool in the consent form. An additional problem arises with photographs and video, as they potentially violate anonymity. We recommend the inclusion of a separate item in the consent form—subjects should be able to opt for participating in the experiment yet request that the video and images will not be made publicly available.

Another ethical consideration is the assignment of credit to the researchers who collected the data. We expect this would take place by citing the original in any paper that refers to data from the shared pool. In the future, copyright mechanisms could be elaborated, probably in the lines of the Creative Common License (CCL; http://creativecommons.org). Existing questionnaires require specific consent for use in an experiment and publishing the questionnaire online. If such consent is not provided, data sharing for that questionnaire would not be possible.

6 Conclusions

We encourage presence researchers to study presence using multiple methods and analysis techniques, and to publish their data, in addition to their results, as we have done in this paper. This will allow the community to analyze and compare experiments as a shared effort, assigning credit where due, of course.

Once more data is available and arranged in a systematic way, we can strive towards additional analysis methods. In particular we encourage researchers to investigate analysis of physiological data. The integration of the different data types presents an interesting challenge. We feel this would allow presence research to be established as a more rigorous scientific discipline by such eventual data publication and sharing.

We regard the next steps as a challenge for the whole community: we hope more researchers will follow by sharing their data and tools, and we expect the need for data standardization and data repositories to become self-evident in that stage. We also intend to continually refine the methodologies mentioned in this paper; some of the recommendations in this paper are a result of our experience, and will only be deployed in our next experiments.

We encourage other researchers to use different methods to analyze the data from our experiment. There are large parts of our data that have not yet been analyzed, or only partially analyzed, and we welcome other researchers to apply other techniques to the data that we have already analyzed.

Finally, we encourage researchers to use this methodology, which relies on large amounts of synchronized recorded data in a mediated experience, beyond presence research; we expect our setting to be useful for researchers in many areas of human research.

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