CONTEXT-AWARE HOARDING OF MULTIMEDIA CONTENT IN A LARGE-SCALE TOUR GUIDE SCENARIO

A case Study on Scaling Issues of a Multimedia Tour Guide

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Abstract: This paper discusses scaling issues of a mobile multimedia tour guide. Making tourist-information available in a substantially large geographical area (e.g. a federal state in Austria) raises new questions, compared to providing similar information in a limited area (such as a museum). First, we have to assume a heterogeneous network infrastructure containing high and low bandwidth links and even total network loss. Video streaming is therefore not possible at any place. Secondly, the total amount of data grows linearly to the number of Points of Interest (POIs) which are augmented by the tour guide. Therefore, a preloading of all data onto a device with limited storage is not possible. A possible solution to these problems is hoarding, i.e. preloading an "appropriate" subset of data. The crucial question is to find the proper subset in dependence of the actual context. The paper discusses the questions of (1) what kind of context information should be considered and (2) what kind of usage patterns can be assumed. Based on these considerations hoarding strategies are developed for the tour guide. The strategies are finally evaluated with real-world data from a federal state wide tourist-card system.

1 INTRODUCTION

Single site mobile tour guides have been a research topic for the last years (Kray and Baus, 2003). Prototype as well as productive systems have shown their abilities to assist tourists in different scenarios. Such tour guides can (depending on their architecture) be easily scaled from a single site or a city with good infrastructure to a larger region if they do not depend on multimedia material and the total amount of required data is therefore low. If a tour guide is intended to heavily use multimedia data and should be scaled over a large area, such as a whole federal state, current mobile storage systems as well as today's available network technologies do not allow a straight forward scalability of such a system.

An example of a single site tour guide with intensive usage of video and audio material was introduced in the MultiMundus project (Kropfberger et al., 2007). The current work utilizes the results of the MultiMundus project and focuses on scaling such a tour guide from a single site to the whole federal state of Carinthia. On the network part the main problems arise due to networks with much too low bandwidths like GSM and GPRS as well as total lack of network access in rural areas. Because Carinthia is located in the Alps, network connectivity is even lower than in other areas due to the alpine shape of the landscape.

Points of interests (POIs) for tourists are often located in alpine environment. Therefore the tour guide must be usable at such places as well. Moreover, often many people (e.g. a group of tourists) use the tour guide in one place at the same time. A naive solution would result in the demand of very high bandwidths in areas where cell-phone networks are intended to be used by few people.

A more sophisticated solution should transfer the needed multimedia data onto the device before the user enters an area with low bandwidth or even unavailability of a network. This could be realized by a sufficiently large storage in each mobile device. If it is possible to store all data in advance no network access will be required at all. This is a really feasible solution for a smaller scenario like a single open-air museum

or leisure park. The feasibility relies on the observation that updates on multimedia data are not very frequent, since video and audio material is usually produced by a production company once per season. However, if storage capacity is limited - i.e. the device cannot store all data of the region - the multimedia material must be intelligently distributed to the mobile clients. This means that at times when the users do have an access to a high-bandwidth network (e.g. at a WLAN hot spot), the system must ensure that the most probably required data is stored on the device. Such data should be transferred in advance. This technique is known as hoarding (Tait et al., 1995).
In addition to multimedia data describing the objects of interest, other data like information about events and weather forecasts are also needed. Such data can nearly always be transferred over cellular networks and this issue is therefore out of scope.
A tour guide can be seen as a classical context aware system. This leads to the idea that the data which should be present on the mobile device depends on the usage context (i.e. the user's current location and interests). Therefore, we introduce and evaluate context aware hoarding strategies to overcome the limitations of network and storage of current mobile devices to realize a state-wide tour guide in Carinthia. The hoarding strategies are evaluated with real tourist movement patterns derived from log data of the Carinthian "tourist card" operator.

The remainder of this work is organized as follows. In Section 2 we present the single-location multimedia tour guide MultiMundus. In Section 3 the problems of scaling the tour guide are discussed in depth. Section 4 discusses related work. In Section 5 hypotheses for a state-wide tour guide are presented. Section 6 introduces the hoarding model used for the tour guide. In section 7 the evaluation environment is presented and the results of the evaluation are shown. Finally, in Section 8 the results of the evaluation are used to make a recommendation for the multimedia data distribution of the tour guide.

2 The M3-Guide

The M3-Guide (Kropfberger et al., 2007) is a multimedia-based guidance system for various consumer devices. The system has a reference implementation called MultiMundus in the leisure park Minimundus[1]. Minimundus is a park with miniatures of famous buildings all over the world. It is also called "The small world at Lake Wörthersee". One can find miniatures of the Eiffel Tower, the Sydney Opera house and many more. The M3-Guide provides video and audio information about these miniatures. The system is context aware in the dimensions *User-Profile*, *Device-Profile*, and *Location*. The presentation is rendered according the user's language, the device's network, and screen properties, as well as the user's current location. The location is sensed by a location aware middleware (Santner et al., 2006) enabling the system to use different location sensing technologies as GPS and Bluetooth transparently.

[1]Minimundus GmbH - http://www.minimundus.at

2.1 Transcoding Media Cache

The leisure park Minimundus is equipped with WLAN allowing the tour guide to get all data over the network. A major problem exists in parts of the park, where the network connectivity is insufficient for video streaming. To solve this issue a transcoding multimedia proxy (TMC) was introduced. The proxy allows a device-specific transcoding and caching of video and audio material on the servers and caching only at the clients. This means that in normal operation the clients play all videos from the local memory. In case of a cache miss the required content is transcoded if necessary - in real time - and transferred to the client.

2.2 Offline Operation

In normal operation the M3-Guide system works in a hybrid way: Textual data of the HTML-presentation are transferred via WLAN; video and audio data are transferred via the TMC. In case of enough storage, they are actually completely loaded from the local storage card of the mobile device. In addition to this hybrid version, an offline version is available where all textual data are also stored on the local memory card. This configuration is the most robust one and needs no investment in network infrastructure.

3 Scaling Issues of a state-wide tour guide

A state wide multimedia tour guide changes the operating environment compared to the MultiMundus scenario completely. While the tour guide is still intended to be used to get detailed information about exhibited objects at points of interest (POIs) the technical basis changes totally. First of all there is no single network technology available with which all data can be transferred at any time. Rather, the situation is shown in Figure 1 where many different

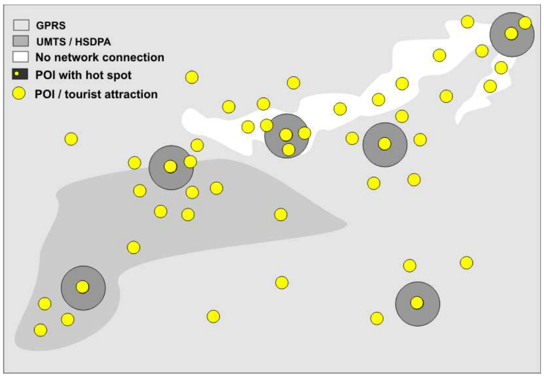

Figure 1: Network situation of the state-wide tour guide

network types may or may not be available depending on the user's location. In contrast to the local tour guide this is not only a technical problem with regard to video content distribution over low-bandwidth links, it is also a question of economics because in networks which are not operated by the tour guide provider high traffic dependent usage fees (Mundt, 2004) must be paid. In addition, the usage patterns of a multimedia tour guide will produce traffic patterns in cellular networks which they are not built for. In alpine and rural environments usually very big cell radiuses are used (Buddendick et al., 2003). This does not cause a problem when only few people transfer data in these areas. But what happens if a full bus of tourists begins a hike and use their personal tour guides to stream different video items more or less at the same time? This scenario is a challenge to today's available public cellular networks in rural, alpine environments.

A different approach to solve the scaling issues is the preloading of all required data in advance. This technique outperformed other solutions in the case of the MultiMundus scenario, due to its high reliability and moderate costs. Unfortunately, the same technique cannot be applied to the state wide tour guide either because there is no memory card or widely available standard that allows memory sizes bigger than 2-32GB. 2GB is the current limitation of standard SD-cards while 32GB is the limit of the emerging High Capacity SD-cards (SD-Group, 2006). Today's practically available 2GB and the future 32GB are definitely more than the card sizes of the MultiMundus project of 512MB. But they are still far too small to operate a single tour guide of all Carinthian tourist attractions.

The limitations of network connections and local memory can be solved if the tour guide system does not deliver all content in advance (offline version) but hoards the potentially required content in advance at WLAN hot spots operated by the tour guide provider. Which data should be hoarded depends on the context, i.e., the user's location, the user's preferences, and her/his history.

4 Related Work

The basis of systems which support continued operation when leaving the network were already discussed in the 1990th when practically no wireless networks existed. The idea of hoarding (Tait et al., 1995) is that the data a mobile computer needs from the network should be stored on the mobile device in advance. The data that should be present on the mobile device when leaving the network is called Hoard-Set. The problem of computing the Hoard-Set is called *Hoarding Problem*. The work in (Kuenning and Popek, 1997) shows a scenario where the Hoarding Problem is solved by the observation of file access patterns. The authors introduce a semantic distance measure between files. This means that files with a low distance to each other should be in the Hoard-Set if one of the files was accessed before leaving the network. In (Kuenning et al., 2002) it was shown that in comparison to automatic hoarding with semantic distance measure even simple LRU hoarding can be nearly equally beneficial. In (Huizinga and Sherman, 1998) and (Kistler and Satyanarayanan, 1992) extensions to current file systems and distributed file systems with hoarding capabilities are presented that support hoarding based on more or less predefined Hoard-Sets.

The presented work focuses on discontinued operations for classical applications. These results are not fully suitable for a context-aware tour guide because the context reflected in these earlier applications is limited to the observations of file access patterns. In a mobile tour guide the usage context is much broader. Therefore, it can be beneficial to use a broad range of context information to compute the hoarding decision. In (Kubach and Rothermel, 2001) a system is presented which is designed to realize a tour guide in a city. It is based on Wireless LAN hot spots. Each hot spot is responsible for a specified area. Based on the past visits, the system calculates which items are needed when the user reaches a hot spot. This means that dependent on the current location of the user visit probabilities for each POI are calculated based on past visits from other users. There are two versions: one with basic visit probabilities and one with more detailed context information provided by external knowledge (e.g., street maps or predefined

routes).
While this system is designed for a tour guide in a single city the system in (Kirchner et al., 2004) is designed to provide up to date information for boat drivers on European water ways. Therefore the geographic distribution is much broader. The system uses the usage context to determine the needed data. In the case of boating this is mainly the type of boat, the current position, the direction, and the speed. The future location of a boat can easily be computed when knowing the actual position, the target place, and type of boat (e.g., max. speed). In addition to this mobile hoarding on the boat, a Web platform is used to predefine the context in form of interests, boat type and target. After defining the context via the Web platform the initial Hoard-Set containing the relevant data is produced. On the boat therefore only changes and new data must be transferred. The system is restricted to boating and is therefore not suitable for our scenario. In contrast to the previous system implementing an actual application, (Feng et al., 2006) shows a general context model which can be used to solve the hoarding problem for a tour guide in a more general way. It is based on an XML context description combined with specified context weights to compute which items are relevant in dependence of actual context dimensions. The paper divides the usage context into the groups: defined, derived, and sensed. Sensed context can be sensed via a sensor (e.g. location by a GPS device), derived context is a context which is derived by other context and defined context is defined by the user. Defined context must be queried from the user or it can be defined globally. When the context is defined by the user it must be considered that the user is willing to define the context (e.g. in form of a questionnaire about interests). In (Kramer et al., 2005) a user context driven tour guide was evaluated and it was shown that users are often not ready to enter detailed context information. Therefore we argue that in our usage scenario detailed context information can be queried from the user to take full advantage of the system from (Feng et al., 2006).

5 Context Considerations for a State-wide Tour Guide

The evaluation in (Kramer et al., 2005) shows that it is not sure that a user wants to input detailed context information. Therefore, a hoarding strategy based on a very detailed user profile does not necessarily result in a better hit rate. In addition, in cases of hoarding it is always possible to define the Hoard-Set manually. Therefore, the time a user needs to define his/her context (e.g., interests) must always be shorter than the time required for a manual definition of the POIs a user wants to visit. If a hoarding strategy would for example rely on a predefined route the hoarding decision should be made manually by the user. Therefore we try to use context information which can be sensed or queried with limited user input. Only if this context information can produce good hoarding results it can be beneficially used for automatic hoarding in the tour guide.

5.1 Static Context

We define static context as context which does not usually change during the visit of the user. Therefore it can be predefined when the user gets her/his tour guide for the first time. This context data should be used to determine what content should be stored on the device before the first usage. We refer to this scenario as initial hoarding.

- **Holiday location:** Tourists usually stay in a specific accommodation (e.g., hotel) in one of 16 regions[2]. We suppose that the region has a strong influence on the visit probabilities of the POIs the user will visit.
- **Season:** We believe that the visit probability of a user changes according to the season.
- **User group:** If there are stereotypes of users like *family visitors*, *senior visitors*, *singles* etc., we suppose that this can be used to define the Hoard-Set as well.
- **Number of travelers:** The number of travelers in a group and the number of children is also static context information.

5.2 Dynamic Context

In contrast to the static context the dynamic context of a user changes during the visit. Therefore, such context items should be used to ensure that the right items are on the device when the user moves around. This scenario is referred to as mobile hoarding. A hoarding decision must always be computed when a user enters a POI which provides a network connection. Therefore data of relevant other POIs without a network connection must be transferred to the mobile device.

- **Current location:** We suppose that the current location has a strong influence on the user's behavior. Therefore, we suppose that people will visit

[2] Source: http://www.kaernten.at

geographically near objects or objects which are often visited in a sequence.

- **User history:** We think that the history of a user has a strong influence on the usage behavior. We assume that visit patterns can be used to determine knowledge about the user's preferences.
- **Weather:** We suppose that the weather conditions have a strong influence on the user's behavior. People usually do not go to the beach in case of cold weather.

6 Hoarding Model

The total amount of data transferred over wireless links should be reduced to a minimum. Therefore we suppose a two-modes hoarding model. First of all, one hoarding decision should be made to choose what data (e.g., multimedia files) should be present on the mobile device when it is used by a specific user for the first time (initial hoarding).
Second, a hoarding decision should be made whenever a user enters a POI with good wireless network access (mobile hoarding). In this case the system must ensure that all relevant data of other POIs - where no network connections can be expected - are located on the device. The relevance is influenced by the context. Our proposed strategies are based on the two major concepts *visit probabilities* and *air distance*.

6.1 Hoarding by visit probabilities

Comparable to the system of (Kubach and Rothermel, 2001) the Hoard-Set is computed by calculating the visit probability of each POI. Therefore the hoarding decision is based on the calculation of the probability that a user visits a POI with regard to a specific context item and value. The calculation of the visit probability can be done straight forward using a simple formula for each POI.

$$t(c) = Total\ number\ of\ visits\ at\ context\ item\ c$$

$$v(c,POI) = Number\ of\ visits\ of\ a\ POI\ at\ context\ item\ c$$

$$p(POI,c) = \frac{v(c,POI)}{t(c)}$$

After the visit probability is computed for each POI the items can be loaded onto the device in descending order of their visit probability. The same formula can be used for initial hoarding as well as for mobile hoarding. The mobile hoarding of new items results in the need for replacement strategies. The replacement strategy of items can be realized by using the reverse order of the calculated visit probabilities.

6.2 Hoarding by Air Distance

The hoarding by visit probabilities requires the tracking of all user sessions. In case of mobile hoarding we suppose that a simple hoarding by air distance might result in high hit rates as well. Therefore, the *n* nearest neighbors (derived from GPS coordinates) of an object should be loaded onto the device. This can additionally be combined with the visit probabilities of the POI.

7 Evaluation

We believe that the movement patterns of the tourists strongly depend on the actual usage context. Therefore, randomized movement patterns do not provide a basis for an adequate evaluation test bed. We decided to use real data of a tourist-card operator in Carinthia called "Kärnten Card". Tourists who pay a comparably low price for the card can visit all affiliated POIs for free or at a reduced price. The system is technically realized as a chip card and terminals at the POIs. For our evaluation we used a log file containing all card usages of one season with about one million card usages. We extracted all sessions from the log file and stored them in a database. We divided the sessions into 20% test sessions and 80% training-sessions. The training sessions were used to compute the visit probabilities with regard to different context items like *weather*, *current location*, *holiday location*. All hoarding algorithms are realized as database queries. As the log file did not contain any further information about the card holders we could not evaluate any predefined interests of the users. We therefore created stereotypes of users via a cluster analysis of the sessions using SPSS (Bühl and Zäfel, 2005). To compute visit probabilities with regard to the actual weather we used the weather service "wunderground" [3]) to get the mean temperature of every day of the season.
The evaluation was finally realized by replaying the test sessions from the log file using different hoarding strategies and different cache sizes.

7.1 Mobile Hoarding

To observe the behavior of mobile hoarding we first tested some simple mobile hoarding algorithms with randomized initialization. Therefore the cache is filled randomly when the tour guide is first used. The

[3]The Weather Underground, Inc - http://www.wunderground.com

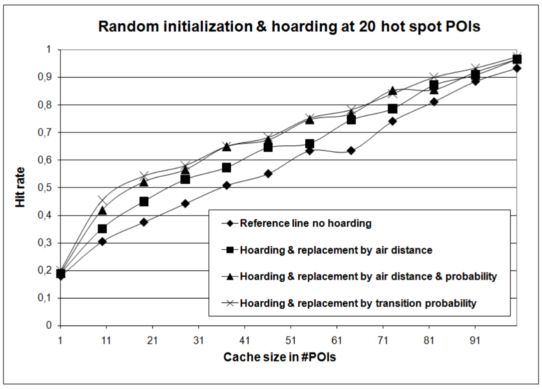

Figure 2: Simple hoarding with randomized initialization

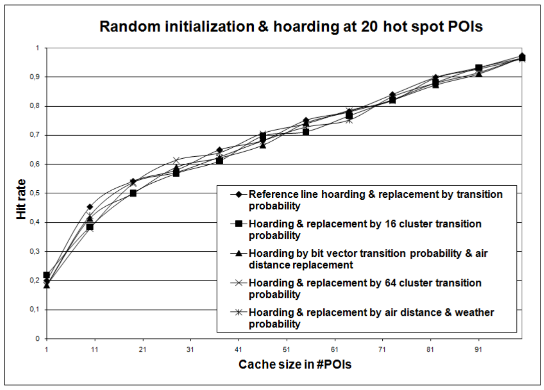

Figure 3: Extended mobile hoarding strategies

result are shown in Figure 2. The reference line (marked by a rhombus) shows the hit rate and cache size when no hoarding is performed. This means that the only way new items get into the cache is that a cache miss occurs at one of the 20 POIs with a hot spot out of the total 107 POIs. Replacement is done according to the air distance (GPS). Items with the maximum distance to the current location are removed. The line marked by a square shows the behavior of mobile hoarding using simple air distance. This means that when entering a hot spot POI the hoarding algorithm checks that at least the 10 nearest other POIs are also stored on the mobile device. This strategy already results in a major improvement of the hit rate of up to 10%.

The air distance is only a heuristics and does not reflect the known visit probabilities in any way. Therefore, we also tested the behavior of a combined strategy using the global visit probability of an object combined with the air distance. The results of this strategy are shown in the line marked by a triangle. This strategy is up to 15% more beneficial than no hoarding. It is very interesting that it comes very close to the much more expensive strategy shown in the line marked by a cross. This strategy uses the transition probability. This means that all visits must be tracked and the probability of a visit of each POI after the visit of each other POI needs to be calculated based on historical sessions. In Figure 3 more advanced strategies are shown. In addition to the simple strategies they use more knowledge about the user context. In real world scenarios this context should be built from user profiles. As no user profile were available, artificial profiles are created by building clusters based on the visit patterns of each session. Thus visit predictions are made on a per group basis. Instead of calculating the probability of a transition from one POI to another globally, only sessions of the same group are used for the computation. The best strategy from Figure 2 is used as a reference. It is marked by a rhombus. Against this strategy a transition probability strategy with 16 and 64 clusters is evaluated. The cluster-based strategies have the main drawback that the clusters cannot be computed a priori in real world scenarios. Therefore, we also tested a method which computes comparable sessions dynamically using a bit vector containing all visits of all sessions. The columns contain bits that indicate the visit of a specific POI. The rows represent a specific session. When a prediction is made only sessions which have visited at least 70% of the POIs visited by the session in question are used for the prediction. We also believe that the visit probability strongly depends on the weather (e.g. indoor museums have many visitors at bad weather). Therefore, we evaluated a strategy which uses the visit probability of different weather conditions. The actual hoarding was therefore realized by the air distance and the visit probability at the current temperature.

Figure 3 shows clearly the surprising result that none of the advanced strategies achieved any significant advantage over simple hoarding by global visit probability and air distance.

7.2 Initial Hoarding

In Figure 4 the results of different initialization strategies without any mobile hoarding at WLAN POIs are shown. The simplest approach is to hoard all data of the POIs according to their global visit probability:

$$p(POI) = \frac{v(POI)}{t(all)}$$

The results are shown in the line marked by a rhombus. A more fine grained strategy (marked by a rectangle) preloads all data of POIs which are mostly vis-

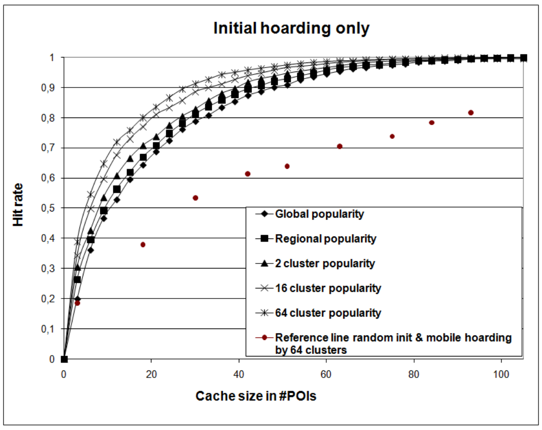

Figure 4: Initial hoarding only

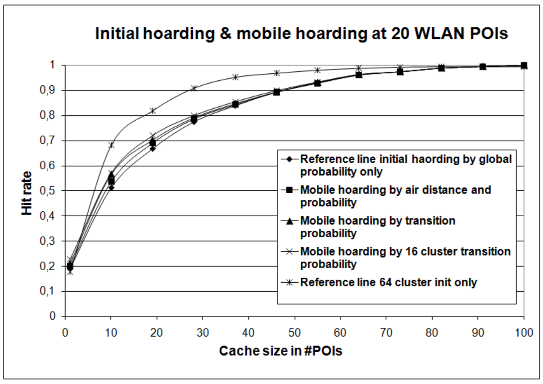

Figure 5: Initial hoarding and mobile hoarding

ited by guests staying in their region:

$$p(POI, region) = \frac{v(POI, region)}{t(region)}$$

It is interesting to see that this approach does not produce significantly higher hit rates. Therefore, we must conclude that people drive all around the state and that they are not bound to the region where they stay. In the next step we computed the visit probability of each POI for each group of users. The groups where simulated by a cluster analysis. We build 2, 16, and 64 clusters. It is interesting to see that even two clusters perform better than the (16) regions.

$$p(POI, group) = \frac{v(POI, group)}{t(group)}$$

The best hit rate can be achieved when using 64 clusters. This pretty high number of clusters might be a problem in a real world scenario. Therefore, it must be noticed that even 16 clusters (which should be practically usable) result in good hit rates. A Hoard-Set size of 40 items results in a hit rate of around 95%. This is about 30% better than the results of the best mobile hoarding strategy with randomized preload. In contrast to the advanced *mobile hoarding* strategies which did not achieve any significant advantage, more complex *initial hoarding* strategies can be used beneficially.

7.3 Initial Hoarding and Mobile Hoarding

For an implementation of the tour guide we assumed that best hit rates should be reachable by combining intelligent initialization and additional mobile hoarding. Figure 5 shows the results of different combined approaches. The reference line (marked by a rhombus) shows the results of a pure initialization by global visit probability without mobile hoarding. The line marked by a rectangle shows the results of a combined approach of hoarding by global visit probability and additional mobile hoarding by the air distance and global visit probability. The - expensive - transition-probability approach performs slightly better than the air distance and global probability approach. The hit rates get a bit better when using clusters. It is interesting that the hit rates are only slightly better than without mobile hoarding. The second reference line (marked by *) shows pure initial hoarding with 64 clusters. This performs much better. A combination of initial hoarding and mobile hoarding does not result in a significantly better hit rate than initial hoarding only.

8 Conclusion and Future Work

This work presented the scaling issues of a multimedia tour guide, expanding from a single location to the whole federal state of Carinthia. Current network and storage technologies do not allow a straight forward scaling for such a tour guide system. Hoarding is a technology which can help to overcome these limitations. In a tour guide scenario automatic hoarding can be based on the user's context. The time a user needs to enter his/her context must not take longer than the time a user would spend to enter the Hoard-Set (POIs she/he wants to visit) manually. We therefore evaluated if it is possible to make a hoarding decision based on context information which can be sensed automatically or requires very limited user interaction. The evaluation was based on real world data provided by the Carinthian tourist card operator. The evaluation has shown that with the evalu-

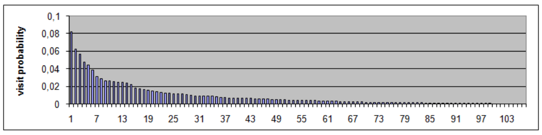

Figure 6: Distribution of visit probabilities

ated data-set, context data and the described hoarding strategies no significant gain for mobile hoarding could be achieved. Suggestions about visitor behavior and corresponding hoarding strategies are of limited value. No strong geographical dependencies could be recognized in the visit patterns. People tend to drive fairly freely throughout the whole state. Even weather conditions do not significantly change the visitors' behavior. It is possible that this surprising behavior is caused by the fact that the "Kärnten Card" is a bonus card with free entry. People might tend to visit all major and most expensive POIs they can. This behavior can also be seen in the total distribution of visits as shown in Figure 6. This figure does also explain why a simple hoarding by global visit probability already produced good results. People tend to visit the top 20 POIs. What else of the other 90 POIs is visited cannot be predicted with the observed context. The good news is that initial hoarding for the tour guide can achieve good hit rates. In contrast to our initial assumptions the region where the user stays for vacation has a comparably low influence on the visit probabilities and thus cannot be used for automatic hoarding in our scenario. We therefore suggest the implementation of a Web platform on which the user can take the hoarding decision manually. This has the additional advantage that no mobile hoarding infrastructure (WLAN hot spots) needs to be installed. Such a Web platform could be integrated into the official tourist web-site of a large area (such as Carinthia in our case). It should be used to identify the relevant POIs for the user and to acquire the user and device context to build a customized tour guide.

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