Supporting Out-of-turn Interactions in a Multimodal Web Interface

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Abstract
Multimodal interfaces are becoming increasingly important with the advent of mobile devices, accessibility considerations, and novel software technologies that combine diverse interaction media. This article investigates systems support for web browsing in a multimodal interface. Specifically, we outline the design and implementation of a software framework that integrates hyperlink and speech modes of interaction. Instead of viewing speech as merely an alternative interaction medium, the framework uses it to support out-of-turn interaction, providing a flexibility of information access not possible with hyperlinks alone. This approach enables the creation of websites that adapt to the needs of users, yet permits the designer fine-grained control over what interactions to support. Design methodology, implementation details, and two case studies are presented.

Keywords: Multimodal interfaces, web interaction on mobile devices, dialog processing engines, mixed-initiative interaction.

1 Introduction
Computing power today is increasingly moving away from the desktop computer to mobile computing devices such as PDAs, tablet PCs, and 3G phones. While posing capacity limitations (e.g., screen real estate, memory), such devices also present possibilities for multimodal interaction via gestures, speech, and handwriting recognition.

An area that is witnessing tremendous growth in multimodal interaction is web browsing on mobile devices. Technologies such as SALT (Speech Application Language Tags) and X+V (XHTML plus Voice) are ushering in the speech-enabled web – documents that can talk and listen rather than passively display content. The maturing of commercial speech recognition engines [15] has been a key factor in the emergence of this niche segment of multimodal browsing.

Speech as a mode of web interaction has become important for primarily two reasons. First, speech permits natural ways to perform certain types of tasks and helps compensate for deficiencies in traditional hyperlink access (which can get cumbersome on small form-factor devices). More importantly, speech-enabled websites help improve accessibility for the more than 40 million visually impaired people in the world today. As a result, using speech leads to the possibility of a conversational user interface [7] that combines the expressive freedom of voice backed by the information bandwidth of a traditional browser.

What exactly would we use a speech-enabled web interface for? The common use of speech on a website is to support navigation of existing site structure via voice [4], in other words as an alternative interaction medium. We posit that this is a rather limited viewpoint and that speech can actually be used to support new functionality at a website. In particular, we show how a multimodal web interface can support a flexibility of information access not possible with hyperlinks alone.
Motivating Example

Consider the following dialogs between an information seeker (Sallie) and an automated political information system.

**Dialog 1**

1 System: Welcome. Are you looking for a Senator or a Representative?
2 Sallie: Senator.
3 System: Democrat or Republican or an Independent?
4 Sallie: Republican.
5 System: What State?
6 Sallie: Minnesota.
7 System: That would be Norm Coleman. First elected in 2002, Coleman ...
   (conversation continues)

**Dialog 2**

1 System: Welcome. Are you looking for a Senator or a Representative?
2 Sallie: Senator.
3 System: Democrat or Republican or an Independent?
4 Sallie: Not sure, but represents the state of Indiana.
5 System: Well, then it is either a Democrat or a Republican, there are no Independents from Indiana.
6 Sallie: I see. Who is the Republican Senator?
7 System: That would be Richard G. Lugar. First elected in 1976, Lugar ...
   (conversation continues)

It is helpful to contrast these dialogs from a conversational initiative standpoint. In the first dialog, Sallie responds to the questions in the order they are posed by the system. Such a dialog is called a fixed-initiative dialog as the initiative resides with the system at all times. The second dialog is system-initiated till Line 4, where Sallie’s input becomes unresponsive and provides some information that was not solicited. We say that Sallie has taken the initiative of conversation from the system. Nevertheless, the conversation is not stalled, the system registers that Sallie answered a different question than was asked, and refocuses the dialog in Line 5 to the issue of party (this time, narrowing down the available options from three to two). Sallie now responds to the initiative and the dialog progresses to complete the specification of a political official. Such a conversation where the two parties exchange initiative is called a mixed-initiative interaction.2

What would be required to support such a flexibility of interaction at a website? It is clear that system-initiated modes of interaction are easiest to support and are the most prevalent in web browsing today. For instance, a webpage displaying a choice of hyperlinks presents such a view, so that clicking on a hyperlink corresponds to Sallie responding to the initiative. The reader can verify that the first dialog above can be supported by a three-level tree-structured HTML site presenting options for branch of congress, party, and state. But how can we support the second dialog, allowing Sallie to take the initiative at a website? This is where speech comes in. If Sallie can talk into the browser, she can provide unsolicited information using voice when she is unable to make a choice among the presented hyperlinks. In addition, if the system can process such an out-of-turn input, it can continue the progression of dialog and tailor future webpages so that they accurately reflect the information gathered over the course of the interaction. We have designed many such multimodal web interfaces, one example is shown in Fig. 1.

It is important to re-iterate that speech input is used here to provide a certain out-of-turn interaction capability at a website. In other words, Sallie is not merely using voice to answer the posed question (although she can do that too), but using it to specify unsolicited information. In the absence of such an out-of-turn facility, the website designer would have to anticipate various user needs and support all possible interaction sequences directly in the
Figure 1: A mixed-initiative interaction with a multimodal web interface.
HTML site structure (e.g., browse by branch-party-state order, browse by branch-state-party order etc.), or provide a
search facility as a method for pruning web pages. The first solution is inelegant due to the mushrooming of choices,
and the second is not desirable either since search facilities usually terminate the dialog and return a flat list of results.
Out-of-turn interaction via speech does not clutter the interface and provides a smooth continuation of the dialog.

We must point out that we are not supporting free-form input of all kinds, only input pertaining to specification
aspects that are not yet solicited by the system. This can be viewed as akin to “looking under the hood, and saying a
hyperlink label that is deeper below.”

2 System Design

Supporting such a natural mode of interaction in a web interface is not an easy undertaking. While technologies such
as SALT and X+V enable the augmentation of speech into browsers, they either operate at a lower level of speci-
fication than the applications considered here, hence significantly increasing programming effort, or are otherwise
limited in their expressive power for creating and managing dialogs. A multimodal web application must build
on these technologies to provide flexible dialog capabilities.

Several considerations emerge in thinking about a software system design for multimodal web interaction. First,
it is important to have uniform processing of hyperlink and voice interaction and, when voice is used, to introduce
minimal overhead in handling responsive versus unsolicited input. Observe that hyperlink access can only be used to
respond to the initiative whereas voice input can be used both for responding and for taking the initiative. Furth-
ermore, a user may combine these modes of initiative in a given utterance – e.g., if the user speaks “Republican Senator
from Minnesota” at the outset, he is responding to the current solicitation as well as providing two unsolicited pieces
of information. Uniform processing of input modalities irrespective of medium (hyperlink or voice) or initiative
(responsive or unsolicited) is thus important to support a seamless multimodal interface. Second, it is beneficial to
have a representation of the dialog at all times, in order to determine how the user’s input affects remaining dialog
options. For instance, in Line 5 of Dialog 2 above, Independents are removed as a possible party choice; in addition
to pruning the hyperlink structure (shown in Fig. 1(c)), we must dynamically reconfigure the speech recognizer to
only await the remaining legal utterances. Third, it must be possible for the site designer to exert fine-grained control
over what types of out-of-turn interactions are to be supported. And finally, it is desirable to be able to automatically
re-engineer existing websites for multimodal out-of-turn interaction, without manual configuration.

2.1 Dialog Representation

We have designed a framework taking into account all these considerations. It is based on staging transforma-
tions – an approach that represents dialogs by programs and uses program transformations to simplify them based
on user input. As an example, Fig. 2(left) depicts a representation of the dialog from Section 1 in a programmatic
notation. You can see that the tree-structured nature of the website is represented as a nested program of conditionals,
where each variable corresponds to a hyperlink that is present in the site. We can think of this program as being
derived from a depth-first traversal of the site. For Dialog 1 of Section 1 the sequence of transformations in Fig. 2
depicts what we want to happen. For Dialog 2 of Section 1 the sequence of transformations in Fig. 3 depicts what
we want to happen.

The first sequence of transformations corresponds to simply interpreting the program in the order in which it is
written. Thus, when Sallie clicks on ‘Senator’ she is specifying the values for the top-level of nested conditionals
(‘Senator’ is set to one, and ‘Representative’ is set to zero). This leads to a simplified program that now solicits
for choice of party. The sequence of Fig. 3 on the other hand, corresponds to ‘jumping ahead’ to nested segments
and simplifying out inner portions of the program before outer portions are even specified. This transformation is
well known to be partial evaluation, a technique popular to compiler writers and implementors of programming
Figure 2: Staging a system-initiated dialog using program transformations. The user specifies ('Senator,' 'Republican,' 'Minnesota'), in that order.

Figure 3: Staging a mixed-initiative dialog using program transformations. The user specifies ('Senator,' 'Indiana,' 'Republican'), in that order.
systems [5]. In Fig. 3 when the user says ‘Indiana’ at the second step, the program is partially evaluated with respect to this variable (and variables for other states set to zero); the simplified program continues to solicit for party, but one of the choices is pruned out since it leads to a dead-end. Notice that a given program when used with an interpreter corresponds to a system-initiated dialog but morphs into a mixed-initiative dialog when used with a partial evaluator.

This is the essence of the staging transformation framework: using a program to model the structure of the dialog and specifying a program transformer to stage it. We write the first dialog as:

\[
\begin{array}{c}
I \\
\text{branch party state}
\end{array}
\]

where the \( I \) denotes an interpreter. Similarly, the second dialog is represented as:

\[
\begin{array}{c}
PE \\
\text{branch party state}
\end{array}
\]

where the \( PE \) denotes a partial evaluator. An interpreter permits only inputs that are responsive to the current solicitation and proceeds in a strict sequential order; it results in the most restrictive dialog. A PE, on the other hand, allows utterances of any combination of available input slots in the dialog. It is the most flexible of stagers.

We will introduce a third stager, called a \textit{curryer} \((C)\) that permits utterance of only valid prefixes of the input arguments. The dialog represented by

\[
\begin{array}{c}
C \\
\text{branch party state}
\end{array}
\]

allows utterance of either ‘branch,’ or (‘branch,’ ‘party’), or (‘branch,’ ‘party,’ ‘state’). In other words, if we are going to take the initiative at a certain point, we must also answer the currently posed question.

These stagers can be composed in a hierarchical fashion to yield dialogs comprised of smaller dialogs, or subdialogs. This allows us to make fine-grained distinctions about the structure of dialogs and the range of valid inputs. In this sense,

\[
\begin{array}{c}
PE \\
a b c d
\end{array}
\]

is not the same as

\[
\begin{array}{c}
PE \\
PE PE a b c d
\end{array}
\]

The former allows all \( 4! \) permutations of \( \{a, b, c, d\} \) whereas the latter precludes utterances such as \(< c a b d \rangle\).

As a practical example of our dialog representation, consider a breakfast dialog involving specification of a \{eggs, coffee, bakery item\} tuple. The user can specify these items in any order, but each item involves a second clarification aspect. After the user has specified his choice of eggs, a clarification of ‘how do you like your eggs?’ might be needed. Similarly, when the user is talking about coffee, a clarification of ‘do you take cream and sugar?’ might be required, and so on. This form of mixing initiative is known as \textit{subdialog invocation} [2]. The set of interaction sequences that address this requirement can be represented as:

\[
\begin{array}{c}
PE \\
e_1 e_2 c_1 c_2 b_1 b_2
\end{array}
\]

where \( e_1, e_2 \) are egg specification aspects, \( c_1, c_2 \) support coffee specification, and \( b_1, b_2 \) specify a bakery item.

The staging transformations framework also specifies a set of rules that dictate how a (dialog, stager) pair is to be simplified based on user input. Notice that this is not as straightforward as it looks as it might require a global restructuring of the representation. Assume that we stage the breakfast dialog using the interaction sequence \(< c_1 e_1 c_2 \ldots \rangle\); the occurrence of \( e_1 \) is invalid according to the dialog specification above, but we will not know
that such an input is arriving at the time we are processing $c_1$. So in response to the input $c_1$, the dialog must be restructured as follows:

$$
\begin{align*}
PE & \xrightarrow{C_1 C_2 C_3} C_1 C_2 C_3 \\
& \Rightarrow C_1 C_2 C_3 PE
\end{align*}
$$

By replacing the top-level PE stager with a C, it becomes clear that the only legal input now possible must have $c_2$. Once the coffee subdialog is completed, the top-level stager will revert back to a PE. Such dialog restructurings are necessary if we are to remain faithful to the original specification. See [3, 13] for formal algorithms to perform such dialog restructurings.

At this point, it must be clear that the staging transformation framework is a powerful representational basis to design dialogs: it has a uniform vocabulary for denoting specification aspects (e.g., each of the slots above could be filled via hyperlink clicks or by voice) and the use of stagers helps us control the mixing of initiative in a very precise manner.

In order to make the staging notation machine-readable, we have defined an XML representation of dialogs called DialogXML. Fig. 4 depicts a minimal DialogXML specification for the politicians example. DialogXML provides elements for defining the slots associated with a dialog, the textual prompts associated with each slot (not shown in Fig. 4), the accompanying vocal prompts and any tapering of them over the course of interaction (also not shown), confirmatory characteristics (whether the user’s response needs confirmation), and constructs for combining basic dialog elements to create complex dialogs. More details about DialogXML and the possible legal specifications are available in [13]. While DialogXML borrows ideas from some tags in the VoiceXML standard [6], the structure of the DialogXML document is more closely modeled after the idea of stagers.

2.2 Site Creation and Content Generation

Having such a representation of the dialog is only the first step. We must create a site to reflect the underlying structure of the dialog and initiate speech processing to recognize the legal utterances as specified in the stager markup. Based on user input, we must simplify the dialog and present personalized content, including facilities for continuing the dialog.

An integrated software framework for this purpose is shown in Fig. 5. Operationally it can be divided into four modules: (i) seeding dialog representations, (ii) staging dialogs, (iii) input and output processing, and (iv)
database connectivity. The idea of seeding dialog representations is to take a dialog specified in our DialogXML notation and create an internal representation, suitable for staging. The staging transformation framework is then used to handle dialog management. The embodiment of these dialogs must contend with voice realizations, hence a significant portion of the framework is devoted to generating grammars for speech output and validating voice input. The framework currently uses the SALT and Speech Recognition Grammars standards to handle voice interaction. Finally, the database operations module manages and streamlines the delivery of web content. Every website is organized as a database that the user initially selects for exploration via out-of-turn interaction. Each record in the database identifies a unique interaction sequence leading to a leaf web page (e.g., Senator Norm Coleman is identified by a record that describes his political affiliations and other addressable attributes).

When the interaction begins, the dialog manager uses the parsed DialogXML and metadata from the database to initialize the representation. The dialog manager must then decide what content to display on the page, the items to offer the user for selection, and the speech prompts to play for the current slot. In addition, the dialog manager must determine what aspects the user may specify out-of-turn. Through an analysis of the dialog representation and a set of SQL queries, it determines this information and generates a HTML page that contains relevant SALT XML objects and references to a suitably generated SRGS grammar. The grammar identifies all the legally speakable utterances for the particular page.

User input from both voice and hyperlinks is uniformly handled by the Utterance Validator module of the system. Upon receiving an utterance from the user, the module first determines whether the utterance contains fillings for multiple slots, and whether the utterance is valid. If part or whole of the utterance was invalid, then the system accepts the valid utterances and rejects the invalid utterances. An appropriate prompt is displayed and played to the user. Having tokenized the user’s utterance into its constituent fillings, the dialog manager then calls the staging transformer with the values for the fillings in the order they were received. After the representation is simplified, the dialog manager applies a suite of dialog motivators [1] (discussed below) to the dialog. If the dialog is not completed, content creation and speech grammar generation resumes.

The system is implemented as a Java web application using JSPs and Servlets. The application runs inside the Tomcat servlet engine. The system uses the Apache HTTPd web-server with a WARP connector to connect to the Tomcat servlet engine, and functions like a proxy-server. A PostgreSQL database server serves the example databases we use in this article. The web-application connects to the database server using the Java Database Connectivity (JDBC) API. It uses a meta-data API to learn about the structure of the data present in the database. An SQL query
initially helps compute a VIEW that serves as the starting point for the dialog. This VIEW is used for all future
interactions and helps reinforce that a user is always working with a personalized ‘view’ of the information space.
The use of VIEWs can be used to increase system efficiency as they can be shared across many users. We tested the
system using the Microsoft SALT plug-in for the Internet Explorer 6.0 browser on a system running Windows XP.

2.3 Dialog Motivators

The only aspect of the architecture to be covered are the dialog motivators and the grammar generators. Dialog
motivators are useful nuggets of processing that help streamline the dialog at every user utterance. We use four main
motivators:

1. **complete-dialog:** This motivator decides if a dialog is complete. A dialog is complete if a unique record in
   the database VIEW being used has been identified, or if there are no more items left to solicit input for in the
dialog. In such cases, the unnecessary slots are removed from the representation.

2. **prune-dialog:** This motivator decides if the internal dialog representation can be pruned as a result of the
   previous utterance by the user. For example, in the case of a pizza dialog, if the user specifies a size of ‘small,’
   and only pepperoni pizzas available in small size, there is no longer a need to ask the user for a topping. Thus
   the topping slot can be automatically filled with ‘pepperoni’ and removed from the dialog representation. While
   the current implementation does not provide the user with notification when a dialog is pruned in this fashion,
such user-feedback is being considered for future work.

   Notice that `complete-dialog` is a specialization of `prune-dialog`.

3. **confirm-dialog:** This motivator applies if the item has been designated in the DialogXML as one for which
   confirmation must be sought. In a real application, confirmation would be sought for utterances that have been
   recognized with a low value of confidence; however SALT does not provide us with the hooks to learn about
   confidence values of recognized utterances, hence we specify the need for confirmation in the DialogXML
   markup.

4. **collect-results:** This motivator applies if the user explicitly requested (via a ‘Show me results’ utterance) that
   the dialog be terminated in order to view a flat listing (of the relevant remaining records).

2.4 Grammar Generation

Grammar generation proceeds in a straightforward manner except for a careful division of labor between the browser,
utterance validator, and the embedded speech grammars themselves. For instance, the system generates JavaScript
to handle some types of interaction on the client side within the browser itself. Confirmation of the user’s utter-
ance, ‘What may I say?,’ and ‘Show me something else’ type of questions are examples of interactions handled by
JavaScript. The embedded SRGS grammars are used for encapsulating site-specific logic and are faithful to the C
and I stager specifications. Generating grammar fragments corresponding to the PE stager will result in an exponential
enumeration of utterance possibilities, so we use a less restrictive grammar and allow the invalid utterances to be
caught by the Utterance Validator instead.

3 Example Applications

Two applications have been created using the out-of-turn interaction framework presented above. The first is an
interface to the Project VoteSmart website [http://www.vote-smart.org] and an example interaction has been already
described in Fig. 1. This interface provides details on about 540 politicians comprising the U.S. Congress.
The second application is an interface to the fuel economy guide at the environmental protection agency (EPA – [http://www.fueleconomy.gov](http://www.fueleconomy.gov)). Th EPA provides raw data on fuel economy statistics about cars available in the United States in a comma separated format (CSV). For this article, we downloaded and reformatted data from the past three years (2000, 2001, and 2002) and loaded it into a PostgreSQL database. The dataset has a total of 2641 records, which translates to approximately 880 records. Upto 26 different attributes can be specified in any interaction with this database. We organized a dialog around three subdialogs. The first is an engine subdialog which solicits (fuel type, information about whether the engine is a gas guzzler, and if it is equipped with a turbo charger and/or a super charger). Another subdialog solicits information about the transmission (whether it is automatic or manual) and the drive (4 wheel or all wheel). The main specification aspects for the car (year, manufacturer, model, number) are included in another subdialog. While there are other ways to organize this information, we initialized the dialog representation as:

\[
PE \\
\text{year class maker model fuel gas super charged? turbo charged? transmission drive}
\]

An example interaction is shown in Fig. 6. It depicts an expert user who knows exactly what he wants, and as a result does not need to engage in a dialog with the system. In a single utterance, he specifies three pieces of information that uniquely identify a car in the database. The dialog manager has applied the prune-dialog motivator to the items in the remaining dialog as these specification aspects are no longer necessary. The system redirects the user to a leaf page, where the user is able to see information about Ford Escort cars manufactured in 2000. This example also shows how the user is able to specify multiple utterances while interacting with the system.

We hasten to add that, for ease of presentation, the screenshots in this article were taken on a Microsoft PocketPC.
simulator. As of this writing, PocketPC does not support SALT and these case studies were actually tested using Microsoft Internet Explorer with the SALT plugin.

4 Discussion

The above applications have highlighted the key features of our software framework. The staging transformers have been primarily responsible for dialog control, specifying what the user may say at any given time. The dialog manager has streamlined the dialog, pruning it when necessary, and triggering the appropriate actions. Our modularized implementation approach makes it easy to construct speech-enabled interfaces to database-driven sites. For want of space, we have not demonstrated several other features of our system such as user response confirmation, tapered prompting, and results collection.

This work helps demonstrate the viability of our view of the speech-enabled web – namely, that of a flexible dialog between the user and the system which allows the user to take the initiative in controlling the flow of the dialog. Rosenfeld et al. [12] have argued that speech interfaces will become increasingly ubiquitous and will be able to support smaller form-factors without compromising usability. The applications presented here validate this viewpoint and help illustrate the importance of using voice to supplement interaction in mobile devices.

It is helpful to contrast our representation-based approach with other ways of specifying dialogs, notably VoiceXML. While they share some similarities, our DialogXML notation is purely declarative and captures only the structure of the dialog. Control is implicitly specified using program transformations, which makes the process of dialog specification less cumbersome for the designer. Furthermore, while VoiceXML permits mixed-initiative dialog sequences too, it does so more as a result of how its form interpretation algorithm (FIA) is organized. Using a combination of program transformation constructs and hierarchically composed dialogs, we are able to specify the nature of out-of-turn interaction in a manner not precisely expressable in VoiceXML (see [11] for more details).

The successful implementation of a dialog-based system [14, 17] requires many more facets such as language understanding, task modeling, intention recognition, and plan management, which are beyond the scope of this work. We are now exploring several directions such as natural language speech input and extending the specification capability of DialogXML. We are also conducting usability studies for our multimodal interfaces and carefully assessing the role of speech as an out-of-turn interaction medium. Especially important is addressing the veritable ‘how do users know what to say?’ problem [16] for multimodal web browsing.

This work is an initial exploration into the use of multimodal interfaces to websites. As the use of browsers that support technologies such as SALT, X+V grows, the importance of software frameworks to support multimodal interaction will only increase.

Acknowledgements

This work is supported in part by US National Science Foundation grants IIS-0049075, IIS-0136182, and by a grant from IBM to explore the use of VoiceXML within their WebSphere product. We acknowledge the helpful contributions of Michael Narayan (who designed the formal rules underlying staging transformations), Robert Capra (for input on speech-enabled interfaces), and Saverio Perugini (who implemented a toolbar version of out-of-turn interfaces [9]).

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