

Chapter 24

Polyphonic Inter-Animation of Voices in VMT

Stefan Trausan-Matu & Traian Rebedea

Stefan.Trausan@cs.pub.ro, Traian.Rebedea@cs.pub.ro

Abstract: This chapter introduces a theoretical framework for analyzing collaborative problem solving in chats, based on the concept of polyphony and Bakhtin's theory of dialog. Polyphony, a notion taken from music theory, may be considered as a general model for interaction and creativity by a group of people ("voices," in an extended sense) following patterns of counterpoint. As Bakhtin emphasized, polyphony may occur in texts; we will show that it can occur in problem-solving chat texts. One of the features of polyphonic music is its potential development of complex architectures starting from a given theme. Polyphonic structuring of dialogs may transform the interaction into a "thinking device": Different voices jointly construct a melody (story or solution), sometimes adopting different positions and then generating, identifying or solving dissonances (unsound, rickety stories or solutions). Polyphony consists of several "horizontal," longitudinal melody lines that are "vertically," transversally integrated. Similarly, in chats, the continuations of utterances are tied together over time providing a melodic line. Simultaneously, they are coordinated with the utterances of others, maintaining the integration toward unity across various themes and variations that sometimes can introduce differences. This chapter also proposes software tools for the visualization of the polyphonic weaving in chats. These tools identify and visualize the explicit and implicit links among utterances, and may determine or visualize the contributions of each participant in a chat.

Keywords: Bakhtin, polyphony, voice, dialog, reference

This chapter introduces a theoretical framework, a method and a visualization tool for analyzing CSCL chats, based on the ideas of polyphonic inter-animation introduced by Bakhtin (1981; 1984a). As in the dialog theory of Bakhtin, we extend

the polyphonic musical model for analyzing language-based interactions, in our case, transcripts of text chats for collaborative learning. Although Bakhtin's ideas are quite well known and considered as a theoretical starting point in the CSCL community (Koschmann, 1999; Stahl, 2006; Wegerif, 2006), there are no elaborations that propose how to use his theory in practice. The analysis method we introduce is inspired from the ideas of counterpoint, which is the theory and methodology used in music for composing and analyzing pieces for multiple instruments or voices. Our theory and method was used for the implementation of a system to analyze and visualize polyphonic threading in chats, proposing an evaluation of the contributions of the participants. This polyphonic perspective shed new light on the dialogic nature of discourse in human language and in problem solving in general. It could also have consequences for the design of collaborative-learning environments.

In polyphony, a number of melodic lines (or "voices," in an extended, non-acoustical perspective, as we will discuss later) jointly construct a harmonious musical piece, generating variations on one or several themes. Dissonances should be avoided and resolved, even if several themes (melodies) or theme variations are played simultaneously, and even if sometimes the voices situate themselves in opposing positions.

Bakhtin considers that multiple voices are present in texts, and sometimes (e.g., in Dostoevsky's novels) they constitute a polyphonic framework (Bakhtin, 1984a). Extrapolating this idea, we observe that inter-animation of voices following polyphonic patterns can be identified in dialogs generally, and in chats in particular. A polyphonic collaboration involves several participants who play several themes and their variations in a game of sequential succession and differing positions. The existence of different voices introduces "dissonances," unsound, rickety stories or solutions. This polyphonic game may eventually facilitate knowledge building through the tension of their opposition and the pressure to resolve the difference (see Chapter 9).

Polyphony, in our view, may be taken as a model of collaboration, in which several participants ("voices") invent, discuss and elaborate ideas—often eventually achieving coherence even if "centrifugal" forces, divergences or differences arise temporarily. In fact, as in physics, centrifugal forces or differences determine a reaction of centripetal forces that act towards increasing unity. Bakhtin identified this centrifugal/centripetal phenomenon in the discourse of novels (Bakhtin, 1981). From a polyphonic point of view, these forces manifest themselves in two dimensions: longitudinal and vertical (melody and harmony).

The above ideas are exemplified in this chapter with chat excerpts for collaborative learning in two domains: mathematics problem solving—investigated in the VMT Project—and human-computer interaction—studied at the Computer Science Department of Bucharest "Politehnica" University. Inter-animation patterns were discovered in the above-mentioned two dimensions: longitudinal (chronologically sequential) and transversal (effectively simultaneous). They move in both dimensions between two opposite trends: unity and difference. Moreover, we consider that even individual thinking can be analyzed as an implicit collaborative

(dialogic) process that involves multiple voices. However, actual collaborations in small groups of different personalities illustrate more explicitly the dialogic process.

The chapter continues with a section that discusses the role of discourse in learning and that introduces the dialogic theory of Bakhtin and polyphony. The following section is dedicated to the presentation and exemplification of the novel polyphonic theoretical model and analysis method of CSCL chats, starting from counterpoint and Bakhtin's ideas. Inter-animation patterns are identified and classified along the longitudinal-vertical and unity-difference dimensions in chats. Software tools that support the identification and visualization of the polyphonic architecture, allowing the analysis of inter-animation and even assessing individual contributions are presented in the fourth section.

Discourse, Dialog and Polyphony

The Role of Discourse in Learning

The assessment of learning achievement in a given domain is often based on evaluating the amount of knowledge acquired by the student, as in question-answering examinations. However, in other cases as in mathematics and other disciplines needing problem-solving abilities and/or creativity, this approach is not adequate. Instead, successful discourse building (e.g., constructing a reasoning chain or writing an essay linking a series of ideas) is required for evaluation. Because discourse is an artifact achieved in communication, discourse-building abilities benefit from social, collaborative learning.

The above two approaches correspond to the contrast between socio-cognitive and socio-cultural theories or between the Intelligent Tutoring System and CSCL paradigms (Koschmann, 1999; Stahl, 2006). The socio-cultural theory of learning is based on Vygotsky, and has had an increasing influence as the limitations of the knowledge acquisition model become recognized. As Hicks noted, "Learning occurs as the co-construction (or reconstruction) of social meanings from within the parameters of emergent, socially negotiated and discursive activity" (Hicks, 1996, p. 136, quoted by Koschmann, 1999). Sfard (2000) remarked, "Rather than speaking about 'acquisition of knowledge,' many people prefer to view learning as *becoming a participant in a certain discourse.*"

Links and Threads

As we have seen above, discourse is a central concept in learning. There are many definitions for discourse, the majority stating that it is characterized by structures beyond a sentence or utterance. One definition that captures ideas present in several others says also: "its main concepts are cohesion—the features that bind sentences to each other grammatically and lexically—and coherence—which is the notional and logical unity of a text" (Newmark, 1988). Therefore, for studying discourse, we must

analyze links and threads (connecting sentences or utterances) providing cohesion and coherence.

In the chat from which an excerpt is presented in Figure 24-1, students at a Human-Computer Interaction course had to discuss facilities and tools for a collaborative environment. The students used the VMT chat environment, which allows the users to explicitly link an utterance to the one it continues or replies to (see Chapter 15). These explicit links are represented in the left part of Figure 24-1 by curly arrows.

In addition to the explicit references, a second type of link may be identified in any text, including chats. It is the case of implicit references among words or phrases. The simplest case of such implicit links is between repeated words, represented in Figure 24-1 by straight lines. In general, these implicit links may be very complex, relating, for example, semantic arguments.

Nr	Ref	Time	User	Text
17		10.26.25	tim	You discussed about a topic separation
18	15	10.26.37	adrian	First of all, the reply method is cumbersome
19	17	10.26.50	john	yes.. because we did not like the way the topics were presented in concert chat
20	18	10.26.56	john	yes !!
21	20	10.27.04	john	i hate double-clicking!
22	20	10.27.18	tim	and how can we find topics?
23	18	10.27.26	adrian	What bothers me is the linear presentation of the discussin
24	23	10.27.43	john	Yep.
25	18	10.27.46	adrian	and double-clicking too
26		10.27.54	tim	You mean u want something like a chat forum? :D
27	24	10.27.58	john	and the reply-to facility is supposed to help you
28	18	10.28.15	adrian	i'd like a tree presentation more
29	18	10.28.38	adrian	or maybe multiple chat columns, for each chat sub-thread
30	27	10.28.58	john	but it is really difficult to use in real-time, because there are so many topics discussed which intertwine each other
31	28	10.29.18	john	i subscribe to a tree-like presentation form
32	P 70	10.29.20	adrian	yes, that's why a clear separation of topics is needed
33	31	10.29.47	adrian	this is easy to implement, no problem here :)
34	30	10.29.49	tim	You need also a clever visual representation
35	30	10.30.05	tim	you'll need also a clever visual interface
36		10.30.22	tim	Who decides the topics?
37	33	10.30.33	john	i suppose you are referring to the visual representation, right?
38	37	10.30.45	john	What i would like is a clever way to separate the topics :)
39	38	10.30.59	john	not just doing it myself manually
40	37	10.31.00	adrian	Yeah
41	39	10.31.44	adrian	When you start a new thread (a new message, non-related to other message), the app can assume a new topic
42	39	10.31.46	john	i would like the application to be able to detect w topic change all by itself

Figure 24-1. Two types of links in the chat.

An interesting thing is that the implicit and explicit links are usually different (e.g., in 21 of the 24 cases in Figure 24-1). This phenomenon might be explained by the fact that the participants probably only felt the need to include an explicit link when an implicit one was not present or obvious. This observation introduces the idea that repetition (e.g., of words or phrases) is a strong interaction pattern that is perceived as such by the participants—as evidenced by the fact that they do not feel the need to introduce explicit links when repetitions of words are present.

Implicit and explicit links form threads. In the case of implicit links between repeated words, this fact is obvious (see Figure 24-1). Threading occurs also for explicit references, indicated by the users, as is seen in Figure 24-2.

Nr	Ref	Time	User	Text
17		10.26.25	tim	You discussed about a topic separation
18	15	10.26.37	adrian	First of all, the reply method is cumbersome
19	17	10.26.50	john	yes, because we did not like the way the topics were presented in concert chat
20	18	10.26.56	john	yes!!
21	20	10.27.04	john	i hate double-clicking!
22	20	10.27.18	tim	and how can we find topics?
23	18	10.27.26	adrian	What bothers me is the linear presentation of the discussin
24	23	10.27.43	john	Yep
25	18	10.27.46	adrian	and double-clicking too
26		10.27.54	tim	You mean u want something like a chat forum? :D
27	24	10.27.58	john	and the reply-to facility is supposed to help you
28	18	10.28.15	adrian	i'd like a tree presentation more
29	18	10.28.38	adrian	or maybe multiple chat columns, for each chat sub-thread
30	27	10.28.58	john	but it is really difficult to use in real-time, because there are so many topics discussed which intertwine each other
31	28	10.29.18	john	i subscribe to a tree-like presentation form
32	P 30	10.29.20	adrian	yes, that's why a clear separation of topics is needed
33	31	10.29.47	adrian	this is easy to implement, no problem here :)
34	30	10.29.49	tim	You need also a clever visual representation
35	30	10.30.05	tim	you'll need also a clever visual interface
36		10.30.22	tim	Who decides the topics?
37	33	10.30.33	john	i suppose you are referring to the visual representation, right?
38	37	10.30.45	john	What i would like is a clever way to separate the topics :)
39	38	10.30.59	john	not just doing it myself, manually
40	37	10.31.00	adrian	Yeah
41	39	10.31.44	adrian	When you start a new thread (a new message, non-related to other message), the app can assume a new topic
42	39	10.31.46	john	i would like the application to be able to detect w topic change all by itself
43	42	10.32.01	tim	That right

Figure 24-2. Multiple parallel threads.

All these threads—in addition to their intrinsic longitudinal nature—due to their co-presence at the same time influence each other, inter-animating in different ways, as we will see later. For example, Figure 24-3 represents a part of the inter-animation process among the three students in the development of the threads of implicit links in Figures 24-1 and 24-2. Time flows from left to right and the same representation of the themes (color and types of lines) is used. In addition to the sequential dimension of theme development, the same figure also represents (with thick arrows) three interactions between themes, which may be considered as transversal interaction patterns (two divergent and one convergent).

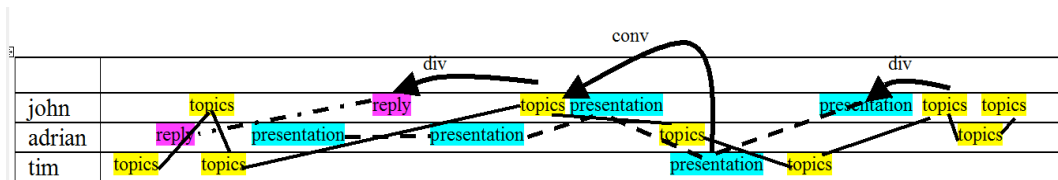


Figure 24-3. The longitudinal-transversal dimensions.

During the chat, each of the participants introduces new variations on the theme of the chat or iterates an already uttered theme variation. For example, in Figure 24-3, three theme variations are emphasized: “replying,” the “topics” in a collaborative chat and ways of “presentation.” Threads may be easily discovered from the obvious repetition pattern of these words.

Similarly to a musical piece, the chats for CSCL have a main theme, a topic that is, for example, the problem to be solved or the product to be designed by the students. This theme generates threads of discussion containing interactions that may be identified and classified according to classes of interaction patterns. These threads contain variations (sub-topics) of the theme, analogous to musical variations. One fundamental issue in polyphony is the presence of several participants (or “voices”) uttering (“singing”) in a unitary way in a given moment. Among the participants, brief dissonances may appear, but these are “solved” and a unity is obtained.

Dialogism and Discourse

Bakhtin considered that, “Any true understanding is dialogic in nature” (Voloshinov, 1973). From his perspective, any discourse may be seen as an intertwining of at least two threads belonging to dialoguing voices. Even if we consider an essay, a novel or even a scientific paper, discourse should be viewed as implying not only the voice of the author. For example, the potential listener also has an important role: The author constructs a thread of ideas, a narrative. Meanwhile, parallel to it, she must take into account the potential flaws of her discourse, the potential questions or replies; she must see it as an utterance that can be disputed by the listener. In this idea, discourse in a novel is similar to dialog in conversation and to polyphony in music, where different voices inter-animate each other.

Voices

The “voice” concept in Bakhtin’s work is central and complex. In the context of a dialog, we understand by a *voice* not the acoustical, physical, vocal expression of a given participant in a dialog but, rather, a distinct position, an utterance, an event or a recurrent series of events of emitting utterances that are heard, remembered, discussed and have influence on the utterances emitted by the other voices. In music, for example, a voice is not fixed to an instrument; the same instrument may play several voices, and different instruments may take the position of a given voice, simultaneously or sequentially.

A voice may be seen as a distinctive position in a group, a person or a group of people who have uttered something, with effects on the subsequent utterances. For example, in Figure 25-1, the voice of John from utterance number 21 is taken up by Adrian, at 25. Moreover, a voice has some particularities; it may have a personality, goals, beliefs, desires and emotions. Consequently, a dialog among several voices is not a dialog among impersonal entities. From another point of view, a voice may become a theme or may contribute to a theme of the discussion.

Polyphony

Discursive voices sometimes weave a polyphonic texture—a feature that Bakhtin admired so much in Dostoevsky’s novels. Bakhtin characterized them as “a plurality of independent and unmerged voices and consciousnesses” (Bakhtin, 1984a).

Polyphony, a concept taken from music, may be considered as a general model for interaction and creativity in a group of human “voices” following counterpoint rules. As Bakhtin emphasized, it may occur also in texts and, as we will show in this chapter, in problem-solving chats. One of the features of polyphonic music is its development of complex architectures starting from a given theme; polyphonic structuring of dialogs may transform them into a “thinking device.”

Polyphony is not only a randomly overlapped set of voices. It also has musicality; it is in fact one of the most complex types of musical compositions, exemplified by the sophisticated contrapuntal fugues of Johann Sebastian Bach.

When there is *more than one independent melodic line happening at the same time* in a piece of music, we say that the music is contrapuntal. The independent melodic lines are called counterpoint. The music that is made up of counterpoint can also be called polyphony, or one can say that the music is polyphonic or speak of the polyphonic texture of the music. (Polyphony, 2005)

In polyphonic music, the melodic, linear dimension does not, in general, disturb the transversal harmony. Even if differential dissonances may appear for a while, they are usually quickly resolved and the unity of the musical piece is restored. This makes a kind of game, which drives (for example, in Bach’s fugues) the inter-animation of the participant voices. The main theme is introduced by one voice, reformulated by others, even contradicted sometimes (e.g., inverted) but all the voices keep a vertical harmony in their diversity, resolving the brief dissonances. The inter-animation is generated by the different conflicting personalities or ideas of the participants. Sometimes the conflicts derive from serious causes (e.g., different approaches for solving a problem), but other times, they derive from pure ludic, playful, carnivalesque (Bakhtin, 1984b) reasons. Dissonances usually appear but they are soon resolved, restoring the global unity.

In each dialogue, similarly to polyphonic music, there are one or more themes, which are debated by the participant voices. Each theme is introduced by a voice and developed by it or by the others. Several themes may be present at the same time in the dialogue, influencing each other.

Starting from Bakhtin’s ideas, we extend the polyphonic, dialogic perspective to collaborative learning. Therefore, we will describe how polyphony may arise in collaborative learning and we will propose ways of analyzing and supporting it in learning environments.

We will use in our further analyses the term “voice” instead of “participant” because it is more general, as mentioned above. In the polyphonic framework for analyzing chats, voice is a central concept, being the point that contrasts with the counter-point. It is not fixed to a person, but, rather, is a position, an idea, a proposal.

The Polyphony of Collaborative-Learning Chats

Computer and communication technologies offer new possibilities for collaboration, by allowing virtual classroom group interaction. New types of artifacts, like hypertext, the World Wide Web, instant messenger chats or discussion forums are changing the classical learning scenarios. In addition to traditional sheets of paper or blackboards for drawing diagrams and writing formulas and sequences of problem-solving steps, computer animations, simulations, chat logs or even virtual participants in the dialog (artificial agents) may now be used for collaboration. It is extremely important to analyze the particularities of discourse in this new context, to identify interaction patterns, and to design supporting software tools. A good example is the fact that in chats we can use a multiply threaded discourse much more easily than in face-to-face conversations.

In order to develop a theoretical background and the associated supporting tools for CSCL chats, we have started from the musical polyphony model and we have looked for analogous structuring in collaborative-learning chats. Next, we have searched for classes of interaction patterns that resemble musical counterpoint rules that are used in composing polyphonic music. Eventually, we have designed and developed tools that would facilitate the analysis from the polyphonic theory.

The analysis and the experiments were performed in two cases: mathematics problem solving and the design of human-computer interfaces. The first case involved students using several different versions of the VMT environment. The language they used was English. The experiments in the second case were performed with college seniors at the Politehnica University of Bucharest (PUB). The students were in a computer science course and they chatted in the VMT environment either in English (as a second language) or in Romanian. All the chat groups had from 3 to 5 participants. The Polyphony system, developed at PUB was used for analyzing the polyphonic structure of all the chats.

Collaborative solving of mathematics problem

Let us consider the following problem from Chapter 5:

Three years ago, men made up two out of every three Internet users in America. Today the ratio of male to female users is about 1 to 1. In that time the number of American females using the Internet has grown by 30,000,000, while the number of males who use the Internet has grown by 100%. By how much has the total Internet-user population increased in America in the past three years? (A) 50,000,000 (B) 60,000,000 (C) 80,000,000 (D) 100,000,000 (E) 200,000,000

This problem was one of a set of eleven problems that were used for an experiment. A group of students had to solve these problems, initially individually, and subsequently collaboratively, using a chat instant messaging system. The above problem was one of the two that were not solved individually by any student but it was successfully solved collaboratively.

Consider Log 24-1, which includes the main utterances that contributed to the finding of the solution of the problem:

Log 24-1.

350	4:31:55	Mic	how do we do this..
351	4:31:59	Mic	without knowing the total number
352	4:32:01	Mic	of internet users?
.....			
357	4:32:23	Dan	it all comes from the 30000000
358	4:32:23	Mic	did u get something for 10?
359	4:32:26	Dan	we already know
360	4:32:44	Mic	30000000 is the number of increase in american females
361	4:33:00	Mic	and since the ratio of male to female
362	4:33:02	Mic	is 1 to 1
363	4:33:09	Mic	that's all i got to give. Someone finish it
364	4:33:10	Mic	Haha
65	4:33:18	Cosi	Haha you jackass
366	4:33:20	Mic	Haha
367	4:33:21	Dan	Hahaha
368	4:33:26	Mic	u all thought i was gonna figure it out didn't
369	4:33:27	Mic	U
370	4:33:28	Mic	huh?
371	4:33:28	Hal	it would be 60,000,000
372	4:33:30	Mic	Hal
373	4:33:31	Mic	its all u
374	4:33:33	Mic	See
375	4:33:34	Mic	i helped
376	4:33:54	Cosi	ok, so what's 11 - just guess on 10
....			
..			
386	4:34:45	Mic	lets get back to 5
387	4:34:47	Cosi	i think it's more than 60,00000,
388	4:34:57	Mic	way to complicate things
389	4:35:03	Cosi	Haha sorry
390	4:35:05	Mic	life was good until you said that
391	4:35:07	Mic	:(
392	4:35:18	Cosi	they cant get higher equally and even out to a 1 to 1 ratio
393	4:35:27	Cosi	oh, no wait, less than that
394	4:35:32	Cosi	50000000
395	4:35:34	Cosi	yeah, it's that
396	4:35:36	Cosi	im pretty sure
397	4:35:37	Mic	Haha
398	4:35:38	Mic	how?
399	4:35:57	Cosi	because the women pop had to grow more than the men in order to even out
400	4:36:07	Cosi	so the men cant be equal (30)
401	4:36:11	Mic	oh wow...
402	4:36:16	Mic	i totally skipped the first sentencwe
403	4:36:16	Cosi	Therefore, the 50,000,000 is the only workable answer
404	4:36:19	Dan	very smart
405	4:36:21	Cosi	Damn im good

Discourse begins with Dan's idea of starting from the 30,000,000 number specified in the problem statement (line 357). It continues with Mic, who seems to start a reasoning path (lines 360-362) by writing typical fragments of mathematical problem-solving speech genre containing the typical phrase "... and since ...". After just three lines, unexpectedly, the reasoning path ends abruptly and Mic states that his discourse is a buffoonery (lines 363-364, 366 and 368-370), taking a "carnavalesque" (Bakhtin, 1984b) direction. This fact is explicitly remarked upon by the utterances of Cosi (line 365) and Dan (line 367). However, even being a pastiche, the "voice" of Mic in his fake discourse fragment has an echo in the succeeding utterances, being continued by Hal, who extrapolates the 1:1 ratio from the present (as stated in the problem) to the whole 3 years, advancing 60,000,000 as a solution (line 371).

Mic continues his buffoonery (lines 372-375), claiming that he helped Hal to find the supposed solution. After a while, Cosi's utterance "i think it's more than 60,00000" appears as an opposing position, a critique, an intuition of something wrong, of some kind of an "unsuccessful story" or some "dissonant" chord. Nevertheless, after less than a minute, she realizes that her own supposition is wrong because the ratio cannot be 1:1 or bigger. This idea drives her to choosing the solution 50,000,000, the single value of the multiple choice answers less than 60,000,000.

We can say that the collaborative discourse enabled Cosi to solve the problem. She didn't solve it in the first phase, when they had to solve it individually. However, when she listened to the discourse proposing a solution (correct in the case of Dan's beginning proposal, fake by Mic and wrong by Hal), she felt the need to take on a different position and she eventually succeeded in solving the problem. Therefore, the discourse acted as a tool, as an artifact that enabled Cosi to find the correct answer. Moreover, we may say that the building of the solution contains the voices of the other participants. They inter-animate, weaving together variations of the starting theme (the problem to be solved), as in a polyphonic musical piece.

Another, no less important feature is the "carnavalesque" character of utterances that eventually gave rise to the solution. The role of carnivalesque utterances was discussed in detail in Bakhtin (1984b).

Polyphonic Structuring in Chat Conversations for Problem Solving

As we have seen in many chapters of this volume, discourse in collaborative problem-solving chats has an obvious sequential, longitudinal, time-driven structure in which the speakers/listeners (readers/writers) are permanently situated and in which they emit their utterances in a threaded manner, having, ideally, a unitary character, oriented toward finding the solution. In parallel with this linear threading dimension, in problem-solving chats the participants also situate themselves in transversal relationships that often adopt critical, differential positions. For example, in the chat excerpt considered in the preceding section, Dan's theme was continued by Mic's buffoonery, continued itself by Hal and then contradicted by a first theme of Cosi's that was subsequently reversed into its opposite.

In this longitudinal-transversal space, voices partake in a unity-difference—or centripetal-centrifugal (Bakhtin, 1981)—dynamic and display various inter-animation patterns. This phenomenon is not specific solely to chats. It also appears in polyphonic music:

The deconstructivist attack—according to which only the difference between difference and unity *as an emphatic difference* (and not as a return to unity) can act as the basis of a differential theory (which dialectic merely claims to be)—is the methodical point of departure for the distinction between polyphony and non-polyphony. (Mahnkopf, 2002)

Interactions of voices towards the unity and difference dimensions were identified in all chats we have analyzed. Some of these interactions may be abstracted in classes of *inter-animation patterns* in which an utterance by one voice triggers an utterance by another voice. In the next section, patterns of inter-animation are identified along the unity-difference dimension. The subsequent section will discuss how these interactions weave into a polyphonic structure.

Inter-Animation Patterns

When somebody listens to Bach’s fugues or other classical music works, one remarks how several themes and their variations are exposed, developed and re-exposed by several instruments. Moreover, these themes and their variations seem to inter-animate each other; even the term musical “fugue” expresses the idea that several voices are “running” and “chasing” each other. The soundscape becomes a playful ground for creativity; a particular type of polyphonic musical piece is called an “invention.”

Bakhtin used the musical metaphor for language, considering that “the voices of others become woven into what we say, write and think” (Koschmann, 1999). Therefore, for analyzing CSCL chats, we investigate how voices are woven in discourse, how themes and voices inter-animate in a polyphonic way. This is important not only for understanding how meaning is created, but also for trying to design tools for support and evaluation.

Specific inter-animation patterns may be identified along each of the unity and difference dimensions in a chat. In CSCL, each of these patterns may be used for automatic abstraction of useful data, either for the participants in a chat, or for teachers for evaluation purposes. Such an application, using natural language processing, is presented in the end of this chapter.

Unity Inter-animation Patterns

Unity-pursuing patterns are characterized by a trend towards continuity and achieving coherence in the chat. A first such class of patterns are *adjacency pairs* (Sacks, Schegloff & Jefferson, 1974), containing couples of logically succeeding utterances like question-answer. The first utterance in an adjacency pair normally requires (in a coherent dialog) the emitting of the second utterance. Examples of

adjacency pairs are utterances 398 and 399 in Log 24-1, or utterances 68-69, 71-72, 73-74, 76-77 in Log 24-2:

Log 24-2.

68	mathisfun	see angle alpha?
69	Bob123	yes
70	Bob123	what about it?
71	mathisfun	is that 60 degrees?
72	Bob123	yes
73	mathisfun	can u use the degree, 2 length to find the last length of a triangle?
74	Bob123	i don't get what you're saying
75	mathisfun	the two arrow pointed lengths and the angle can find the length A
76	Bob123	by what?
77	mathisfun	the two sides and the degree

Question-answer adjacency pairs are important in learning because they force the students to participate, to face questions, to answer and, implicitly, to reason and understand the discussed problems.

Other kinds of adjacency pairs may be identified, for example, greeting-greeting (19-20, 21-22 in Log 24-3):

Log 24-3.

19	john:	hi all
20	Dan:	hi john
21	mary:	happy birthday, john!
22	john:	Thanks mary!

In CSCL, specific adjacency pairs have been identified. For example, Stahl (2006, ch. 21) identified *math proposal adjacency pairs*, with the structure:

1. An individual makes a proposal to the group for the group's work.
2. Another member of the group accepts or rejects the proposal.

A second kind of unity inter-animation pattern is *repetition*, which plays an important role in creating coherence in a discourse. Repetition generally involves a larger number of utterances than an adjacency pair. Tannen (1989) considers that repetitions may be seen as a kind of rhythm making, with a main role of enhancing the involvement of the participants in a dialogue. Of course, repetition and rhythm are features with strong links with music, enforcing our analogy. Log 24-4 (which is a transcript of a face-to-face conversation, taken from (Stahl, 2006, p. 250)) exemplifies these ideas:

Log 24-4.

1:21:53	Teacher	And you don't have anything like that there?
1:21:56	Steven	I don't think so
1:21:57	Jamie	Not with the same engine
1:21:58	Steven	[No
	Jamie	[Not with the same
1:21:59	Teacher	With the same engine ... but with a different (0.1) ... nose cone?=

1:22:01	Chuck	[=the same=
	Jamie	[=Yeah,
1:22:02	Chuck	These are both (0.8) the same thing
1:22:04	Teacher Aw	[right
1:22:05	Brent	[This one's different

Socialization or jokes are also a way of creating unity. For example, many times participants in chats feel the need to joke, probably for establishing a closer relation with the other participants, perhaps in order to establish a group flow state (Csikszentmihalyi, 1990). In fact, in all the chats we examined there is always a preliminary socialization phase.

Another interaction pattern is *cumulative talk* (Mercer, 2000) or, in Sacks' words, *collaborative utterances* (Sacks, 1962/1995). In such a situation, several participants jointly utter a sentence, like a single person. Log 24-5 shows a collaborative utterance co-constructed by three people completing each other's contribution (Sacks, 1962/1995, p 144-145):

Log 24-5.

Joe	(cough) We were in an automobile discussion,
Henry	discussing the psychological motives for
Mel	drag racing on the streets

A second example of cumulative talk is the inter-animation of Mathpudding and Mathman in a VMT problem-solving chat (Log 24-6):

Log 24-6.

117	ModeratorSf	could you guys tell templar what's going on?
118	mathpudding	we're experimenting with circles
119	mathman	and finding as many possible relations as we can

The last unity inter-animation pattern we will discuss here is *convergence*, which is an utterance that links two discussion threads having different topics. For example, in Figure 24-1, the utterance 34 links the discussion thread on “(re)presentation” with the one on “topic.” Convergence is an extremely important pattern, considered by Roschelle (1996) the crux of collaboration. It is the single transversal pattern among the previous, longitudinal ones.

Difference inter-animation patterns

Difference patterns are inherent to chat conversations. Disputes or negotiations are inter-animated by differences and opposing positions. Difference making has a crucial role in chats for collaborative learning, a role that may be best understood from a polyphonic, musical perspective. The possibilities of contemplating (listening, reading) from a critical position the ideas (melodies) of other people and entering into negotiation and argumentation (polyphony of voices) enhance problem solving and enable learning through a trial-and-error process. Such processes also

appear in individual learning (we can say that thinking also includes multiple inner voices), but the presence of multiple participants enhances both the possibility of developing multiple threads and, meanwhile, of identifying differences. The inter-animation of the multiple perspectives of the participants, their opposition as a result of contemplation, the presence of a third opinion in cases of conflict, and sometimes the synthesis it brings are better aids to success than a multi-voiced discourse performed by an individual (as inner thinking), where there is inherently much less conflict.

Several classes of difference inter-animation patterns may be identified. There are simple, obvious differential utterances that dismiss an assertion (Log 24-7):

Log 24-7.

371	4:33:28	Hal	it would be 60,000,000
.....			
387	4:34:47	Cosi	i think it's more than 60,00000

There might be difference making that not only disapproves an assertion but also proposes a development (Log 24-8):

Log 24-8.

392	4:35:18	Cosi	they cant get higher equally and even out to a 1 to 1 ratio
-----	---------	------	---

Sometimes, the participants even explicitly state that they found a difference and describe it (Log 24-9):

Log 24-9.

P4nzer	agree with me so far?
Tricavl	yes, but i did the same thing
Tricavl	the difference was the place of the space :).
petry_g	and the number of moves :)

Another example of this last type of difference making is Log 24-4 used above for the exemplification of repetitions. It ends with an extremely important difference making, which, in fact, is the moment of finding the solution (Stahl, 2006). Actually, we could say that learning is achieved in many situations by understanding significant differences.

Evidence that participants make their own (internalize, individualize) a differential position is also provided by the statistics of personal pronoun usage in chat sessions. For example, in a corpus of chats recorded in May 2005, “I” was used 727 times, much more than the usage of “we,” with 472 occurrences. First person “me” was used 84 times comparing to “us,” used only 34 times. However, the second person addressing is very well represented by 947 uses of “you.”

Automatic Analysis and Graphical Representation

The polyphony-based theoretical framework presented above may be used for developing automated analysis and visualization tools for examining chats from different points of view. As previously discussed, we consider a *voice* as a particular position, which may be taken by one or more *persons* when they emit an *utterance*, which has *explicit* and *implicit* links or *influences* on the other voices. In the implementation of our analysis tool, we start from the utterances in the dialog, we identify themes by detecting recurrent concepts and, in addition to explicit links, stated by the referencing facility of VMT, we try to find implicit links, reflecting voices' influences. These implicit links are detected by searching for instances of the possible interaction patterns discussed above. Eventually, we try to measure the influence of each participant in the chat, considering the “strength” of their voices (positions, uttered utterances) on the subsequent utterances, according to the existing links. Computational linguistics techniques are used for the identification of the themes and of implicit links among utterances.

Identification of Chat Themes

Chat themes are identified using text-mining techniques. The first step in finding the chat subjects is to strip the text of irrelevant words (stop-words), text emoticons—like “:)” or “:P”—special abbreviations used while chatting (e.g., “brb,” “np” and “thx”) and other words considered irrelevant at this stage.

The next step is the tokenization of the chat text. Recurrent tokens and their synonyms are considered as candidate concepts in the analysis. Synonyms are retrieved from the WordNet lexical ontology (<http://wordnet.princeton.edu>). If a concept is not found on WordNet, mistypes are searched. If successful, the synonyms of the suggested word will be retrieved. If no suggestions are found, the word is considered as being specific to the analyzed chat and the human analyst is asked for details. In this way, the analyst can tag the part of speech for each word and can add synonyms. All this information is saved into a cache, so the analyst will not be prompted twice for the same word.

The last stage for identifying the chat topics consists of a unification of the candidate concepts discovered in the chat. This is done by using the synonym list for every concept: if a concept in the chat appears in the list of synonyms of another concept, then the two concepts' synonym lists are joined. At this point, the frequency of the resulting concept is the added frequencies of the two unified concepts. This process continues until there are no more concepts to be unified. At this point, the list of resulting concepts is taken as the list of topics for the chat conversation, ordered by their frequency.

In addition to the above method, used for determining the chat topics, there is an alternate technique we used to infer them by using a surface analysis technique of the conversation. Observing that new topics are generally introduced into a conversation using some standard expressions such as “let's talk about email” or “what about wikis,” we

can construct a simple and efficient method for deducing the topics in a conversation by searching for the moment when they are first mentioned.

A list of patterns of ways of introducing topics in a conversation can be manually edited. If an utterance matches any one of the patterns, it means that the utterance introduces a new topic. A pattern consists of a number of words that must be identified in the utterance and a key word that is associated to the new topic of the conversation (e.g., “let’s talk about <topic>” or “what about <topic>”). The process of identifying a pattern in an utterance is done using the synset for each word that has already been extracted from WordNet.

The implemented system has an interface (see Figure 24-4) that lists the topics sorted according to their number of occurrences in the chat. This interface also displays the utterances of the chat associated with the topics they include and with information about the detected interaction patterns (e.g., adjacency pairs). It also contains some parameters that can be tuned for obtaining the best analysis.

The screenshot shows the 'Polyphony - chat analysis' interface. It is divided into several sections:

- General Settings:** Includes fields for 'Input File Name' (E:\projecte\k-teams\PLNProject\TranscriptParser\bin\Debug\StefanPaper.htm), 'Output File Name' (voices_representation.txt), and 'Automatic Topics Min Freq' (3). There are checkboxes for 'Show details', 'Use Google suggestions', and 'Ask for unknown words', and a 'Chat type' dropdown set to 'Type 2'. Buttons for 'PARSE', 'Output Graphics', 'Graphical Representation', and 'Ontologies' are present.
- Voices representation settings:** Includes sliders for 'Implicit Factor' (0.20), 'Reference Factor' (0.33), 'Agreement Factor' (0.50), 'Disagreement Factor' (0.33), 'Min Utterance Value' (1.00), and 'Agreement Penalty Factor' (0.50).
- Chat info:** Shows 'Participants' as 'azemel vmtModerator_Nan stefan Jsarmi gerry wes murat terry cprose Jim_Waters dennysj'.
- Topics:** A table listing detected topics with their frequencies.

Index	Topic	Frequency
1	>>>voices<<< vocalization vocalisation vocalism phonation vox articulation spokesperson interpreter representative part sound vocalize vocalise	25
2	>>>voice<<< vocalization vocalisation vocalism phonation vox articulation spokesperson interpreter representative part sound vocalize vocalise	18
3	>>>individual<<<	15
4	>>>role<<< function office part character theatrical_role persona purpose use	14
5	>>>metaphor<<<	14
6	>>>thread<<<	14
- Utterances Information:** A table showing details for each utterance.

Index	ID	RefID	Author	Text	Voices	Abs value	Miscellaneous
65.1	-	-	-	>>>-<<<	-	-	-
66	82	72	stefan	:yes, Bakhtin's theory is that every text contains a series of voices	Ref = gerry	0.134	(AGREEMENT)
66.1	-	-	-	>>>Bakhtin's<<<	-	-	-
66.2	-	-	-	>>>theory<<<	-	-	-
66.3	-	-	-	>>>text<<< textual_matter textbook text_edition schoolbook school_text	-	-	-
66.4	-	-	-	>>>contains<<< incorporate comprise hold bear carry control hold_in che...	-	-	-
66.5	-	-	-	>>>series<<< serial serial_publication	-	-	-
66.6	-	-	-	>>>voices<<< vocalization vocalisation vocalism phonation vox articulation...	-	-	-
67	83	71	terry	:I?m with Nan here. I wonder if this isn't a slightly off-base metaphor. In p...	Ref = vmtModerator_Nan	0.120	(QUESTION) (AGRE...
67.1	-	-	-	>>>m<<< meter metre molarity molar_concentration thousand one_thous...	-	-	-
67.2	-	-	-	>>>Nan<<< nan_river	-	-	-
67.3	-	-	-	>>>wonder<<< wonderment admiration marvel curiosity inquire enquire a...	-	-	-

Figure 24-4. Topic detection screen.

The topics of the chat may also be detected as the connected components in the chat graph described in the next section. All the details of an utterance in the chat—the content of the utterance, the implicit and explicit references and other details—can be visualized by clicking the rectangle representing the utterance.

Discovering Implicit Links in an Utterance

As we have previously discussed, in a log of a VMT conversation two types of links among utterances may be identified. There are explicit links, stated by participants by means of the VMT referencing tool. In addition to these, many implicit links may be identified, as was exemplified in Figure 24-1.

We consider that each chat utterance may have a certain influence in the development of the conversation; it can become a chat voice. Each utterance may contain the influence of at least one other, alien voice, for example that to whom it refers, as an answer to a question, an elaboration, a disagreement, etc. By transitivity, voices may accumulate during a conversation. The emitter of the utterance implicitly can note the presence of alien voices in his utterance, when he explicitly refers to a previous utterance with the VMT referencing tool.

Because users are generally in a hurry or they don't consider it necessary, many of the utterances do not have any explicit references. Thus, it is necessary to find a method for discovering the implicit references in an utterance. The method proposed here is similar to the one presented above for determining the introduction of new chat topics, based on text mining techniques (Manning & Schutze, 1999) and patterns. The system uses another list of patterns that consists of a set of words (expressions) and a local subject called the referred word. If an utterance matches one of the patterns, it is first determined what word in the utterance is the referred word (e.g., "I don't agree with your assessment"). Then, a search for this word is performed, in a predetermined number of the most recent previous utterances. If such a word is found in one of these utterances, then an implicit relationship is defined between the two lines, the current utterance referring to the identified utterance. In addition, two other empirical methods were implemented.

A graphical representation of chats was designed to facilitate an analysis based on the polyphony theory of Bakhtin and to permit the best visualization of the conversation. For each participant in the chat, there is a separate horizontal line in the representation and each utterance is placed in the line corresponding to the issuer of that utterance, taking into account its positioning in the original chat file—using the timeline as an horizontal axis (see Figure 24-5). Each utterance is represented as a rectangular node having a horizontal length proportional with the textual length of the utterance. The distance between two different utterances is proportional to the time between the utterances (Trausan-Matu et al., 2007).

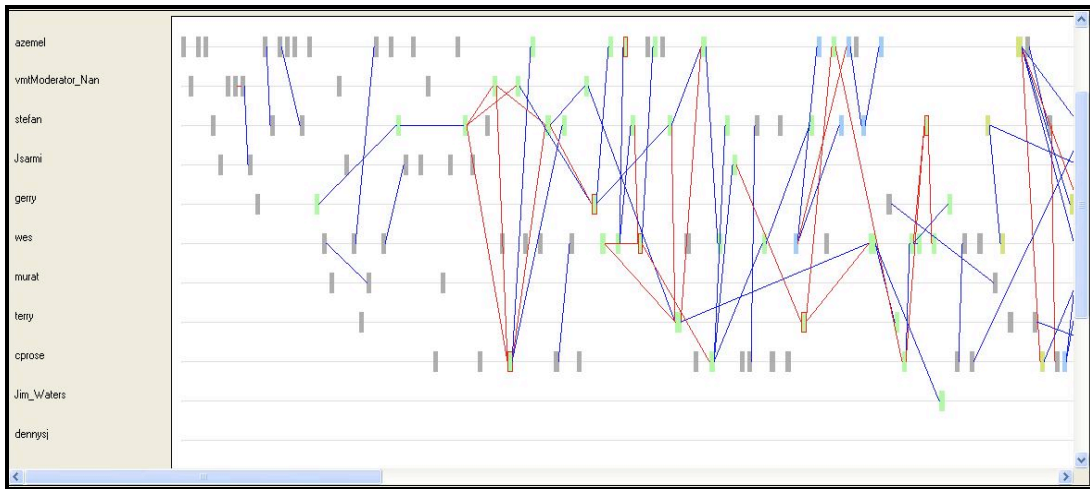


Figure 24-5. Graphical visualization of the discussion threads.

The explicit references between utterances are depicted using blue connecting lines while the implicit references (deduced using the method described in Trausan-Matu *et al.*, 2007) are represented using red lines. The utterances that introduce a new topic in the conversation are represented with a red margin.

The graphical representation of the chat has a scaling factor that permits an overview of the chat, as in Figure 24-6, as well as an attentive observation of the details in a conversation (as in Figure 24-5).

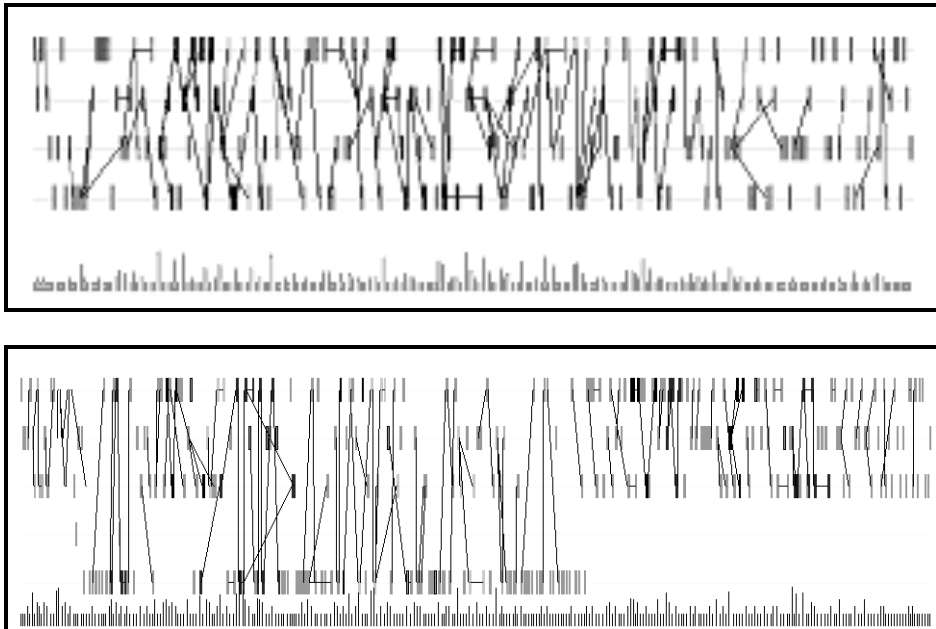


Figure 24-6. A conversation with (a) equal and (b) non-equal participation.

Viewing the whole conversation graph gives an idea of the global participation of the learners. For example, in Figure 24-6a, all the participants make about an equal

number of contributions. This is not the case in Figure 24-6b, where one participant has almost no participation and another student leaves early in the chat session.

At the bottom of the graphical representation of the conversation (see Figure 24-7), after the line corresponding to the last participant in the chat, there is a special area that represents the importance (strength) of each utterance, considered as a chat voice, in the conversation (Trausan-Matu et al., 2007). The height of the rectangle corresponding to each utterance is proportional with the strength of that utterance (or voice). The details about how this measure is computed are presented in the next section.

Assessing the Contributions of the Learners in the Conversation

One of the most important goals in any collaborative-learning process is the assessment of the contribution of each learner. For CSCL using chat conversations, in order to determine the contributions of the participants a graphical representation of the contribution was implemented starting from the polyphonic theory and the analysis method. The evaluation of the contributions of each learner considers the degree to which they have influenced the conversation. In terms of our polyphonic model, we evaluate to what degree they have emitted strong utterances that influenced the following discussion, or, in other words, to what degree the utterance became a strong voice.

An utterance is considered strong if it influences the continuation of the conversation. The contribution of each participant is computed by accumulating the strengths of the utterances they emitted.

The automatic analysis considers the inter-animation patterns in the chat. It uses several criteria such as the presence in the chat of questions, agreement, disagreement or explicit and implicit referencing. The diagram is generated using a series of parameters like: implicit and explicit reference factors, bonuses for agreement, penalties for disagreement, minimum value for a chat utterance, penalty factors for utterances that agree or disagree with other utterances if these utterances have less originality than the first ones. In addition, the strength of a voice (of an utterance) depends on the strength of the utterances that refer to it. If an utterance is referenced by other utterances that are considered important, obviously that utterance also becomes important.

By using this method of computing their importance, the utterances that have started an important conversation within the chat, as well as those that began new topics or marked the passage between topics, are more easily emphasized. If the explicit relationships were always used and the implicit ones could be correctly determined in as high a number as possible, then this method of calculating the contribution of a participant would be considered successful (Trausan-Matu et al., 2007).

During the first step of the graph generation, the importance value of each utterance is computed by relating it to an abstract utterance that is built from the most important concepts in the conversation (the themes). When constructing this utterance, we take into account only the concepts whose frequency of appearance is

above a given threshold. Then all the utterances in the chat are scaled in the interval 0-100, by comparing each utterance with the abstract utterance. The comparison is done using the synonym sets of each word contained in the utterance. Thus, this process uses only the horizontal relations from WordNet. An utterance with a score of 0 contains no words from the concepts in the abstract utterance and an utterance with a score of 100 contains all the concepts from the abstract utterance.

Log 24-10 contains a sequence of utterances where the participants collaborate intensively (it may be considered as a “collaborative moment” (Stahl, 2006)), a fact revealed from the relations graph (Figure 24-6) and from the large number of explicit and implicit relations interconnecting utterances 122 through 136.

Log 24-10.

122	RaduDumitrescu	also the application allows the user to describe the topic of the meeting	
123	Alexrosiu	yes, and furthermore, several topics should be defined	Reference to message No. 122
124	Alexei	yes, that would also help an automatic application to parse the ch	Reference to part of the message No: 122
125	RaduDumitrescu	so everybody must know what are the meeting is all about	
126	Alexrosiu	maybe even some users could be waned if they are offtopic... but this is a rather sci-fi feature, i guess :)	Reference to message No. 124
127	RaduDumitrescu	and at the end the application should specify if all the topics were covered... what do you think?	Reference to message No. 123
128	Alexei	yes, i agree, but I think it can be done if the user is going too “offtopic”	Reference to part of the message No: 126
129	Alexei	yes, maybe some percentage of coverage...	Reference to part of the message No: 127
130	Alexrosiu	Correct	Reference to message No. 127
131	Dorin	this feature implies a rather advanced natural language processing engine, though	Reference to message No. 128
132	Alexei	so, about the reminders - when a user leaves the conference for some reason, he should be reminded about the missed parts of the conversion	Reference to part of the message No: 121
133	Alexrosiu	maybe some kind of reminders should be set for future conferences... meaning that all people invited to the conference should be reminded to attend	
134	Alexei	a problem that i've also noticed here is the rather unsynchronized way of talking	
135	Alexrosiu	well, this would be solved by using the tree view i was talking about earlier	Reference to message No. 134
136	RaduDumitrescu	i think the users can check the topics, no need for natural language processing	Reference to message No. 131

From Figure 24-7, we can see that the highest strength (the highest rectangle below the utterances) has the voice of RaduDumitrescu at the utterance nr. 122 (an oval shadow was manually added for emphasizing it). This fact is also observable by the large number of relations following utterance 122 (see Log 24-10) and in the change of the amount of contribution of RaduDumitrescu, in Figure 24-8.

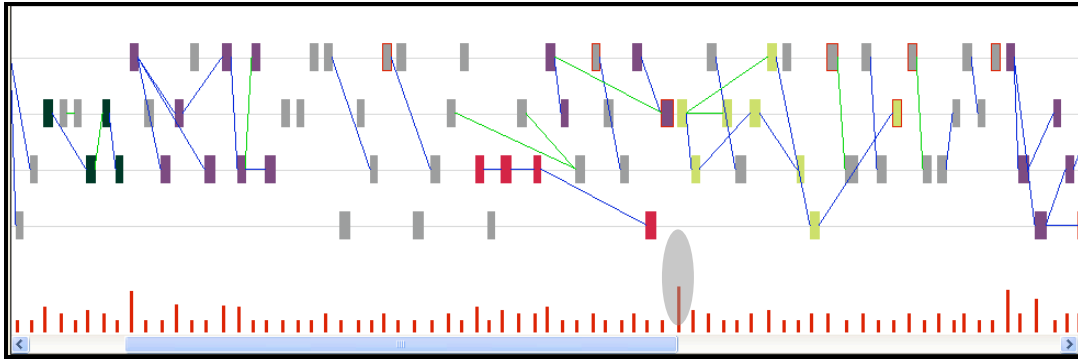


Figure 24-7. Utterances 122-136 are linked with many relations.

The graph that shows the contributions of every participant (in Figure 24-8) contains on the x-axis the utterances in the chat and on the y-axis the value computed for each participant in the conversation, for his/her cumulative contribution. This value is computed by summing the numerical values corresponding to the strengths of the utterances that the participant has uttered up to the position on the x-axis. Accordingly, for each utterance, at least the value of one user contribution is modified—the value for the user that issued that utterance.

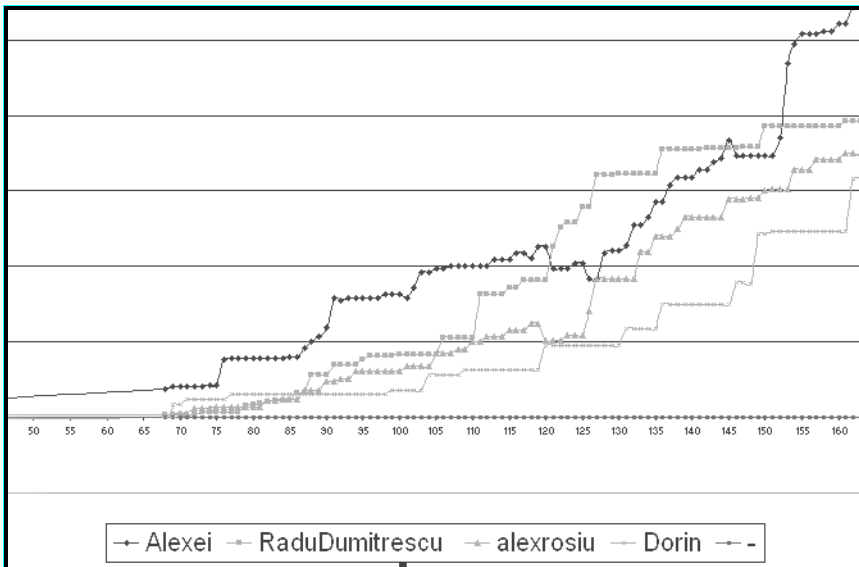


Figure 24-8. The evolution of the contribution of the participants in the chat.

Conclusion

In all of the chats from the CSCL experiments we have analyzed, the interactions are structured in a polyphonic manner. Discourse in chats implies an inter-animation of multiple voices along two dimensions, the sequential utterance threading and the transversal one, similar to polyphonic music. In addition, another dichotomy, the unity-difference (or centrifugal-centripetal, (Bakhtin, 1981)) opposition may also be observed. Adjacency pairs, repetitions, collaborative utterances, socialization and convergent inter-animation patterns contribute to the unity-directed dimension at diverse discourse levels.

The second, differential dimension could be better understood if we consider discourse as an artifact that—taking into account that every participant in collaborative activities has a distinct personality—is a source of a critical, differential attitude. Even if individual, inner discourse may be multi-voiced, difference and critique are empowered in collaborative contexts, in a community of different personalities.

A consequence of the unity-differential perspective for the design of CSCL environments is that they must facilitate inter-animation not only on the unity dimension through threading, but also along the transversal, differential, critical dimension. Tools that can assist in this category should be able to provide abstractions of the discourse and recommendations, in order to facilitate differential position taking. They should also allow the participants to emphasize the different proposed themes and to relate them in threads, polyphonically.

Wegerif advocates the use of a dialogic framework for teaching thinking skills by stressing inter-animation: “meaning-making requires the inter-animation of more than one perspective” (Wegerif, 2006). He proposes that “questions like ‘*What do you think?*’ and ‘*Why do you think that?*’ in the right place can have a profound effect on learning” (Wegerif, 2007). However, he does not develop the polyphonic feature of inter-animation.

Starting from the theory of dialog, an application was implemented that may be used for inspecting what is going on and for measuring the degree to which learners are involved in a forum discussion or a chat conversation. The effective contribution of each participant to the inter-animation process may be measured. The application visualizes the strengths of the voices of the participants in chat conversations, following Bakhtin’s ideas. Diagrammatic representations are used for viewing the influence of a given speaker and of the comparative evolution of the contribution of the learners. The visualization application described here can be further extended to consider more aspects related to the polyphonic, contrapuntal features of chat conversations.

References

- Bakhtin, M. (1981). *The dialogic imagination: Four essays*: University of Texas Press.
- Bakhtin, M. (1984a). *Problems of Dostoevsky’s poetics* (C. Emerson, Trans.). Minneapolis, MN: University of Minnesota Press.

- Bakhtin, M. (1984b). *Rabelais and his world* (H. Iswolsky, Trans.). Bloomington, IN: Indiana University Press.
- Csikszentmihalyi, M. (1990). *Flow: The psychology of optimal experience*: Harper Collins.
- Hicks, D. (1996). Contextual inquiries: A discourse-oriented study of classroom learning. In D. Hicks (Ed.), *Discourse, learning and schooling* (pp. 104-141). New York, NY: Cambridge University Press.
- Koschmann, T. (1999). *Toward a dialogic theory of learning: Bakhtin's contribution to learning in settings of collaboration*. Paper presented at the Computer Supported Collaborative Learning (CSCL '99), Palo Alto, CA. Proceedings pp. 308-313: Lawrence Erlbaum. Retrieved from <http://kn.cilt.org/cscl99/A38/A38.HTM>.
- Mahnkopf, C. S. (2002). Theory of polyphony. In C. S. Mahnkopf, F. Cox & W. Schurig (Eds.), *Polyphony and complexity*. Hofheim, Germany: Wolke Verlag.
- Manning, C., & Schutze, H. (1999). *Foundations of statistical natural language processing*. Cambridge, MA: MIT Press.
- Mercer, N. (2000). *Words and minds. How we use language to think together*: Routledge.
- Newmark, P. (1988). *A textbook of translation*. Hertfordshire, UK: Prentice Hall.
- Polyphony. (2005). Polyphony. Retrieved from <http://cnx.rice.edu/content/ml1634/latest>.
- Roschelle, J. (1996). Learning by collaborating: Convergent conceptual change. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 209-248). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sacks, H. (1962/1995). *Lectures on conversation*. Oxford, UK: Blackwell.
- Sacks, H., Schegloff, E. A., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language*, 50(4), 696-735. Retrieved from www.jstor.org.
- Sfard, A. (2000). On reform movement and the limits of mathematical discourse. *Mathematical Thinking and Learning*, 2(3), 157-189.
- Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press. Retrieved from <http://GerryStahl.net/mit/>.
- Tannen, D. (1989). *Talking voices: Repetition, dialogue, and imagery in conversational discourse*. Cambridge, UK: Cambridge University Press.
- Trausan-Matu, S., Rebedea, T., Dragan, A., & Alexandru, C. (2007). Visualisation of learners' contributions in chat conversations. In J. Fong. & P. Wang (Eds.), *Blended learning* (pp. 217-226): Pearson-Prentice Hal. Retrieved from http://www.cs.cityu.edu.hk/~wbl2007WBL2007_Proceedings_HTML/WBL2007_PP217-226_Trausan-Matu.pdf.
- Voloshinov, V. (1973). *Marxism and the philosophy of language*. New York, NY: Seminar Press.
- Wegerif, R. (2006). A dialogical understanding of the relationship between CSCL and teaching thinking skills. *International Journal of Computer-Supported Collaborative Learning (ijCSCL)*, 1(1), 143-157. Retrieved from http://ijcscl.org/preprints/volume1_issue1/wegerif.pdf.
- Wegerif, R. (2007). *Dialogic, education and technology: Expanding the space of learning*. New York, NY: Kluwer-Springer.