VERBAL PARADIGMS—PART II: COMPUTING WITH VERBS

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Memorandum No. UCB/ERL M97/66

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Verbal Paradigms—Part II: Computing with Verbs

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September 18, 1997

Abstract

In part-I of this series, verbs are modeled by using linear and nonlinear dynamic systems for characterizing each of them with different dynamics in different contexts. In this paper the problem of computing with verbs (verb computation) is studied. The relationship and computation between verbs are modeled by relations between different dynamics. The classical "equality" is generalized to verb equality, which is synchronization or generalized synchronization between dynamic systems. Different schemes of synchronization between dynamic systems are presented to show how rich the verb equality can be. Simulation results are provided. Verb computation turns out to be another aspect of linguistic computation besides fuzzy logic. In a word, fuzzy logic answers the questions characterized by "what" while verb computation answers the questions characterized by "how". Verb computation is a model of the natural way that used by human beings to cope with the dynamic aspects of complexities of the nature. Whenever (wherever) a system becomes too complex to get exact model, and only some linguistic statements containing descriptions or implications of dynamic characteristics exist, verb computation becomes a powerful tool for coping with these complexities. Comparing with fuzzy theory, which copes with vagueness in static relations, verb computation copes with vagueness in dynamic processes. Fuzzy theory and verb computation describe two different aspects of the complexity we should cope with for our survival. To illustrate the application of verb computation, the simulation example of "understand music" is presented to show how emotions and intuitions can be transmitted through music by a process of computing with verbs.

1 Introduction

At first, we pose a problem on how can we *understand* the verbs that other individuals used to imply some emotions, feelings or intuitions? There should exist many different methods to model this problem. The simplest way is to use "equality". This kind of equality is used by modern digital computers where a "copying" operation is supposed to make the machine "have knowledge." This kind of machine intelligence is a static map. Since "equality" in the conventional sense is only a static map between two processes, it is not rich enough to describe different interactions between verbs (dynamic processes) in different contexts. When a human being "understands" other individuals, it seems that the resulting understandings are varying with different contexts. In one word, the verb "understand" is much richer than a static equality though it connects closely to the concept of "equality". In fact, there exist many verbs, which have the characteristics of equalities. Some of them are "know", "feel", "recognize", "perceive", "be aware of", "learn" and "comprehend". Although these verbs have different functions in our natural language, they share one common characteristic, i.e., they are used to describe dynamic processes in which human individuals get their experiences, intuitions or knowledge. By using these verbs, an individual is aware of a kind of "copying" process happening in his brain. In this "copying" process, he assumes that he is getting some equivalent copies of something from his counterpart.

We need a systematic method called *verb computation* (or, *computing with verb*) to build the relationship between different verbs or between verb and circumstance. The verb computation is a framework of organizing and processing the implied information behind dynamics of verbs. Since verbs are dynamic processes, the verb computation should be also dynamic process in some prescribed contexts. The verb computation may also degrade to conventional computations and fuzzy computations. I will focus on the dynamic aspects of verb computation in this paper.

In our natural language systems, we have already developed some explicit methods of verb computation. For example, we use adverbs to modify dynamics of verbs such that the modified verbs satisfy desired objectives. In this sense, adverbs are systems whose inputs are verbs (dynamic processes) and outputs are modified dynamic processes. This property of adverb is also used to modify adjectives, which are extensively studied in fuzzy theory[4].

Before verb computation can be defined in a mathematical framework, a quantitative description of each verb should be used. We use an *evolving function* (or *evolving system*) to describe a verb. Since the time is so deeply rooted in our brain and our reality, it is convenient to define an evolving function as an explicit function of time. In different contexts, evolving functions(systems) may be defined by simple functions or complex behaviors of nonlinear dynamic systems. For example, let us study the following sentence:

$\boxed{\text{Gina usually } \textit{goes} \text{ to school by bus.}}$

where the evolving function of "go" can be found by tracing the route and time schedule of bus. In this case, "go" is a simple process which can be observed explicitly. However, in most cases, verb computation involving some processes which can not be easily observed. This may pose a big problem on finding evolving functions of verbs. For example, let us study the following sentences:

$\boxed{\text{Gina } \textit{smiles} \text{ to me in her eyes.}}$

while smiling on face may be easy to observe by monitoring the facial movements, it is difficult to observe how can a person smile by using eyes though we all have this kind of experience. There exist much more uncertainty in the evolving function of this "smiling" in eyes because its understanding is based on the personal experience of the observer.

Anyhow, it is time for human being to design a new generation of computers, which can answer the problem

$\boxed{\text{How are you } \textit{feeling}\text{, Dr. Computer?}}$

by computing but not programming. This is a verb computation problem of a verb "feel".

In this paper I also want to present a verb computation-based model for describing the intuitive connection between human individuals. There are different methods to set up the intuitive connections between human individuals. Music is one of these methods. Music is said a form of communication between human individuals beyond words (where the words end the music begins). But what is music from a physical point of view? It is a *dynamic process* characterized by $1/f$ spectrum. The dynamics behind a piece of music may be periodic, quasi-periodic or even chaotic. Musicians can really code their feelings and emotions into this kind of "noise" and audiences with trained ears can decoded the feelings and emotions in their own ways. This kind of communication via music between human individuals is very similar to a dynamic process called *adaptive synchronization*[3]. In this case, the synchronization happens in high neural levels (high brain functions). In this paper, we show how this happens when a chaotic signal (a kind of music) is transmitted between two individuals.

The organization of this paper is as follows. In Section 2, the dynamic equalities of verbs(verb equalities) are modeled by synchronizations. In Section 3, the verb computation is used to model a process of understanding music. In Section 4, some concluding remarks are given.

2 Equality and similarity between verbs

Before we can provide verb computation, the most important thing is to define verb *equality*. Equality is an elementary axiom in any computation framework though some of them embedded it in implicit ways. However, classical equality is an idealized concept, which can not find in the nature. In a word, equality can only exist in our mental experiments. When we consider the static aspects of the nature, this kind of mental idealization of equality may be useful to handle computations of static objects. But the verb computation is used to handle with dynamic aspects of the nature, the idealized equality is not suitable in this framework. If the idealized equality is used in verb computation, then the rich dynamics and the resulting complexities of our natural language will be destroyed.

2.1 Verb equalities

In our natural language, the *equality* and *similarity* are represented by a kind of verb such as "understand" and "feel". We model this kind of verb by using dynamic processes called *(generalized) synchronizations*. For example, examining the following sentence:

Mary *feels* what Tom *feels*.

We can define a synchronizing process between the feelings of Mary and Tom. If Mary can "feel" what Tom "feels" exactly, then both of them are intuitively connected, in this case, we can not distinguish the feelings of both, we call this process an *identical synchronization*. Identical synchronization is a generalization of the classical equality by combining dynamics into it. If what Mary "feels" is not exact the copy of what Tom "feels", but these two feelings are correlated, then a *generalized synchronization*(GS) is needed in this situation. We use the following two examples to show difference between this two kinds of synchronizations.

Example 1. Identical synchronization

Given the evolving function of "feel" from Mary as

$$feel_{Mary}(t) = \sin(t + \pi) \tag{1}$$

and that from Tom as

$$feel_{Tom}(t) = \sin(t + \pi) \tag{2}$$

we have

$$feel_{Mary}(t) = feel_{Tom}(t) \tag{3}$$

this is the identical synchronization and the classical equality, which means that Mary and Tom "feel" the same thing. In this case, identical synchronization degrades to classical equality. However, identical synchronization may be a dynamic process as shown in Section 2.2.

Example 2. General synchronization

Given the evolving function of "feel" from Mary as

$$feel_{Mary}(t) = 2\sin(t + \pi) \tag{4}$$

and that from Tom as

$$feel_{Tom}(t) = \sin(t) \tag{5}$$

we have

$$feel_{Mary}(t) = g(feel_{Tom}(t)) \tag{6}$$

where

$$g(x(t)) = 2x(t + \pi) \tag{7}$$

is called *GS transformation.* This is a GS which is connected by a GS transformation. The GS transformation itself can be a chaotic system if the verbs are modeled by chaotic systems, such as "I *think* what you *think*" or "I *am thinking* what you *dreamed* last night".

To summarize this section I emphasize that verb equalities, which include different types of synchronizations, are dynamic processes. A verb equality is a system characterized by either synchronization errors in the cases of identical synchronizations or some kinds of correlation functions in the cases of generalized synchronizations.

2.2 Examples of verb equalities

We then study how can two verbs be synchronized. Without loss of generality, we use a chaotic system, the Lorenz system[2], to demonstrate the synchronization between two verbs. The state equation of a Lorenz system is given by

$$\begin{cases} \dot{x} = -\sigma x + \sigma y \\ \dot{y} = rx - y - xz \\ \dot{z} = xy - bz \end{cases} \tag{8}$$

where σ, r, and b are three real positive parameters.

2.2.1 Identical synchronization

Example 1

We first consider the identical synchronization of two verbs, which are modeled by two Lorenz systems. The first thing we should specify is the manner of interconnections between these two verbs. If these two verbs occur during an active conversation between two individuals such that each of them is affected by its counterpart in this conversation, then we can use a mutual coupling between two Lorenz systems to model the interconnections of these two verbs during the conversation.

1. The evolving system of Verb 1

$$\begin{cases} \dot{x} = -\sigma x + \sigma y + k(\tilde{x} - x) \\ \dot{y} = rx - y - xz + k(\tilde{y} - y) \\ \dot{z} = xy - bz + k(\tilde{z} - z) \end{cases} \tag{9}$$

2. The evolving system of Verb 2

$$\begin{cases} \dot{\tilde{x}} = -\sigma \tilde{x} + \sigma \tilde{y} + k(x - \tilde{x}) \\ \dot{\tilde{y}} = r\tilde{x} - \tilde{y} - \tilde{x}\tilde{z} + k(y - \tilde{y}) \\ \dot{\tilde{z}} = \tilde{x}\tilde{y} - b\tilde{z} + k(z - \tilde{z}) \end{cases} \tag{10}$$

where k is used to model the mutual influence between two verbs. These two verbs are coupled by feeding states to each other.

The simulation results are shown in Fig.1 with $k = 1$. In Fig.1(a) the evolving processes of $x(t)$ and $\tilde{x}(t)$ are shown. The solid waveform and the dashed waveform show $x(t)$ and $\tilde{x}(t)$, respectively. In Fig.1 (b) the evolving processes of $y(t)$ and $\tilde{y}(t)$ are shown. The solid waveform and the dashed waveform show $y(t)$ and $\tilde{y}(t)$, respectively. In Fig.1 (c) the evolving processes of $z(t)$ and $\tilde{z}(t)$ are shown. The solid waveform and the dashed waveform show $z(t)$ and $\tilde{z}(t)$, respectively. We can see that these two verbs influence each other such that they go to the same process after about 6 time unit. This simulation is an example of the implementation of the verb in the following sentence:

Mary and Tom *understand* each other (in their conversation).

Example 2

In some contexts, the influence between two verbs is uni-directional. For example, one read a book and try to understand the verbs in the book. Since the verbs in the book can not affected by the reader, the understanding of the verbs by the reader is a uni-directional synchronizing process. One example of verb equality using uni-directional coupling is as following:

1. The evolving system of Verb 1, which is printed in a book and fixed.

$$\begin{cases} \dot{x} = -\sigma x + \sigma y \\ \dot{y} = rx - y - xz \\ \dot{z} = xy - bz \end{cases} \tag{11}$$

2. The evolving system of Verb 2, which is the understanding of Verb 1 by the reader.

$$\begin{cases} \dot{\tilde{x}} = -\sigma\tilde{x} + \sigma\tilde{y} + k(x - \tilde{x}) \\ \dot{\tilde{y}} = r\tilde{x} - \tilde{y} - \tilde{x}\tilde{z} + k(y - \tilde{y}) \\ \dot{\tilde{z}} = \tilde{x}\tilde{y} - b\tilde{z} + k(z - \tilde{z}) \end{cases} \tag{12}$$

The simulation results are shown in Fig.2 with $k = 2$. In Fig.2(a) the evolving processes of $x(t)$ and $\tilde{x}(t)$ are shown. The solid waveform and the dashed waveform show $x(t)$ and $\tilde{x}(t)$, respectively. In Fig.2 (b) the evolving processes of $y(t)$ and $\tilde{y}(t)$ are shown. The solid waveform and the dashed waveform show $y(t)$ and $\tilde{y}(t)$, respectively. In Fig.2 (c) the evolving processes of $z(t)$ and $\tilde{z}(t)$ are shown. The solid waveform and the dashed waveform show $z(t)$ and $\tilde{z}(t)$, respectively. Although the simulations in both Figs.1 and 2 have the same synchronization error system and with the same initial condition, the simulation results are totally different. Comparing the results in Fig.1 we can see that the "equalizing" process when the Verb 1 is "fixed" is much faster than when both Verb 1 and Verb 2 are subject to simultaneous modifications. This simulation is an example of the implementation of the verb in the following sentence:

Mary *understands* what Tom wrote.

2.2.2 Generalized synchronization

While full understanding is a goal we always try to achieve, misunderstanding is the most common case in our conversation. Misunderstanding is also a kind of understanding though it may be not "correct"(or identical to the original one). In this sense, there should be some other verb equality for modeling this kind of non-perfect understanding. On the other hand, since the richness of the personalities of individuals different understandings to the same object are inner factors contributed to the variety of our society. The variety of behaviors, which can not happen in classical equalities, is another aspect of verb equality. The model for this kind of variety is GS. The coupling between two verbs in generalized synchronization can also be mutual or uni-directional. For saving space, only the cases of uni-directional coupling are presented in this section.

Example 1

In this example, the verb equality only distorts the original dynamics with a scalar factor. This can be used to model the verbs in the following sentence:

When she reads these sentences, (the reader) Mary *feels* what (the author) Tom *felt* when he was seriously hurt in that accident.

Although Mary can using her mental experiment to reconstruct some virtual aches, she should not be hurt by reading these sentences as serious as Tom was. This two "feel's" may be qualitatively similar but not necessary to be the same. The quantitative difference and the qualitative similarity is another aspect of verb equality, which can be modeled by the following GS.

1. The evolving system of Verb 1, which is fixed.

$$\begin{cases} \dot{x} = -\sigma x + \sigma y \\ \dot{y} = rx - y - xz \\ \dot{z} = xy - bz \end{cases} \tag{13}$$

2. The evolving system of Verb 2, which is the understanding of Verb 1 by the reader.

$$\begin{cases} \dot{\tilde{x}} = -\sigma\tilde{x} + \sigma\tilde{y} \\ \dot{\tilde{y}} = \lambda(r-\mu)x + \mu\tilde{x} - \tilde{y} - \lambda xz \\ \dot{\tilde{z}} = \lambda xy - b\tilde{z} \end{cases} \tag{14}$$

The simulation results with $\lambda = 0.5$ are shown in Fig.3. Figure 3(a) shows the attractor of Verb 1. Figure 3(b) shows the attractor of Verb 2. We can see that the attractor of Verb 2 is a scaled version of that of Verb 1 by a scaling factor $\lambda = 0.5$. Figure 3(c), (d) and (e) show the relations of x verse $\tilde{x}$, y verse $\tilde{y}$ and z verse $\tilde{z}$, respectively.

Example 2

In this example, the verb equality distorts the original dynamics with a linear transformation. This can be used to model the verbs in the following sentence:

When she reads these sentences, Although (the reader) Mary *does not understand* why, she *knows* that (the author) Tom was right in some way.

Although Mary does not fully understand what she is reading, she feels something, which may be a transformation of the original one. This "know" may be a very complex system, e.g., chaotic system, which functions as a GS transformation. To avoid clutter, only the case with linear GS transformation is presented in this example. In this case, "know" is a kind of verb equality.

In this example, the Verb 1 is the same as that used in Example 1, the evolving system of Verb 2 is given by

$$\begin{aligned} \dot{\tilde{x}} &= -\sigma\tilde{x} + \sigma\tilde{y} + \sigma x(r - \mu - z) \\ \dot{\tilde{y}} &= \mu\tilde{x} - \tilde{y} - x(r - \mu - z) \\ \dot{\tilde{z}} &= -b\tilde{z} - bxy \end{aligned} \tag{15}$$

If the GS between Verb 1 and Verb 2 is achieved, the following relations should be satisfied:

$$\begin{aligned} \tilde{x} &= -\sigma x + \sigma y \triangleq f_1(x, y) \\ \tilde{y} &= \mu x - y \triangleq f_2(x, y) \\ \tilde{z} &= -bz \end{aligned} \tag{16}$$

The simulation results are shown in Fig.4. Fig.4(a) shows the attractor of Verb 2. One can see that this attractor is totally different to the famous "butterfly" attractor as shown in Fig.3(a) though the former is only a linearly transformed version of the latter. Figs.4(b) and (c) show the plots of $\tilde{x}$ verse $f_1(x, y)$ and $\tilde{y}$ verse $f_2(x, y)$, respectively. One can see that the linear GS transformation is true. Fig.4(d) shows the plot of $\tilde{z}$ verse z. To demonstrate the difference between GS and identical synchronization, we also show the $\tilde{x}$ verse x plot and $\tilde{y}$ verse y plot in Fig.4(e) and Fig.4(f), respectively. The verb equality based on GS is more flexible than the identical synchronization-based verb equality because some kinds of personalities are allowed here in verb computation.

3 How music as a tool to transfer our feelings and emotions

In this section, an application of verb computation based on verb equality is presented. We use verb computation to model intuitive connections between human individuals via music.

Although music is usually simpler than a chaotic signal, for the purpose of demonstrating, I suppose that there exists a kind of chaotic "music", which is generated by the following chaotic system[1]:

$$\begin{cases} \dot{x} = \frac{1}{\alpha}[G(y-x) - f(x)] \\ \dot{y} = \frac{1}{\beta}[G(x-y) + z] \\ \dot{z} = -\frac{1}{\gamma}(y + Kz) \end{cases} \tag{17}$$

where $\alpha = 5.56 \times 10^{-9}$, $\beta = 50 \times 10^{-9}$, $\gamma = 7.14 \times 10^{-3}$, $G = 7.20461 \times 10^{-4}$ and $K = 2$ are constant parameters. $f(\cdot)$ is given by

$$f(x) = b(t)x + \frac{1}{2}(a(t) - b(t))(|x+1| - |x-1|) + c(t) \tag{18}$$

where $a(t), b(t)$ and $c(t)$ are time-varying parameters.

We suppose that the emotions or feelings of a musician are used to tune some parameters of his brain such that different tones are generated. For example, "play happily" is encoded by the the following parameter dynamics:

$$a_{play\ happily}(t) = -0.9 \times 10^{-3}(1 - 0.01\sin(300t)) \tag{19}$$

"play anxiously" is encoded by

$$b_{play\ anxiously}(t) = -0.5 \times 10^{-3}(1 - 0.01\sin(100t)) \tag{20}$$

"play calmly" is encoded by

$$c_{play\ calmly}(t) = 5 \times 10^{-6}\sin(75t) \tag{21}$$

Then we assume that music is given by the state variable $x(t)$ because sound is an one-dimensional signal. Since the same genetic structure of brain, we suppose that an audience has the following chaotic system, which functions as the biological basis for understanding music, in his brain:

$$\begin{cases} \dot{x}_1 = \frac{1}{\alpha}[G(y_1 - x_1) - f_1(x_1) + d(x - x_1)] \\ \dot{y}_1 = \frac{1}{\beta}[G(x_1 - y_1) + z_1] \\ \dot{z}_1 = -\frac{1}{\gamma}(y_1 + Kz_1) \end{cases} \tag{22}$$

where

$$f_1(x) = b_1(t)x + \frac{1}{2}(a_1(t) - b_1(t))(|x+1| - |x-1|) + c_1(t) \tag{23}$$

We can see that the chaotic system of the audience has almost the same structure as that of the musician except that an additional term $d_1(x - x_1)$ is embedded in the first equation. The additional term in Eq.(22) is reasonable for modeling the "driven" effect of the music to the audience. Since the model of the musician in Eq.(17) is used to model the fact that the "music is coming out from the heart of the musician", there does not exist outer "driven" music to drive the musician for new music. In this sense, the musician is an autonomous system while the audience is a forced system.

We suppose that initially, there exist some differences between parameters of the two brains of the musician and the audience. These parameter differences are reasonable because before the audience can sink into the emotional status of the musician, we can not expect that they share a similar emotional status.

When the music is heard by the audience, we suppose that there exist dynamic processes in the audience corresponding to "play happily", "play anxiously" and "play calmly" of the musician. Since the audience can not "play" the music, we choose a verb "listen" to describe the passive position of the audience when he try to "understand" ("enjoy", or whatever) the music.

Then the problem is how the audience to "listen", of course, from our experiences we know different ears have different understandings of the same piece of music. For example, for a traditional Chinese, some American jazz and rocks are really very strong noises and the American village songs are acceptable. In this paper, I only study the case that the audience can totally "understand" what the musician try to transmitted. Here, "understand" is a verb equality. To do this, "listen" can be modeled as the following dynamic systems:

$$\dot{a}_{1\ listen\ happily} = -\frac{1}{2}\alpha\phi_1(x - x_1)(|x_1+1| - |x_1-1|) \tag{24}$$

$$\dot{b}_{1\ listen\ anxiously} = \alpha\phi_2(x - x_1)\left(x_1 - \frac{1}{2}(|x_1+1| - |x_1-1|)\right) \tag{25}$$

$$\dot{c}_{1\ listen\ calmly} = -\alpha\phi_3(x - x_1) \tag{26}$$

where $\phi_1 = 5 \times 10^9$, $\phi_2 = 5 \times 10^9$ and $\phi_3 = 5 \times 10^9$ are three constants.

A "pay-attention" is used to model the process that how can the audience try to catch the important details in the music by using time-varying attention weight given by

$$\dot{d}_{pay\ attention} = \alpha\phi_4(x - x_1)^2 \tag{27}$$

where $\phi_4 = 10^9$ is a constant. The initial conditions in the simulation are given by: $a_1(0) = -0.01 \times 10^{-3}$, $b_1(0) = -10 \times 10^{-3}$, $c_1(0) = 0.1 \times 10^{-3}$ and $d(0) = 0.08 \times 10^{-3}$. The forth-order Roung-Kutta method with 10^{-6} fixed step is used.

To summarize, we have model the whole process which is called "understand music" as the following verb computation:

understand music $\triangleq$ emotions and feelings of musician modeled by verbs "play happily", "play anxiously" and "play calmly" $\Longrightarrow$ "play" music $\Longrightarrow$ the audience "pays" attention to details of the music $\Longrightarrow$the audience "listens" happily, anxiously and calmly corresponding to the music from the heart of the musician $\Longrightarrow$the audience gets the same emotions and feelings of the musician.

In the simulation, we present the result when the musician has time-varying emotions during his playing of the music. The simulation is shown in Fig.5. Figure 5(a) shows the waveform of the music $x(t)$ which is really complex. Figures 5(b), (c) and (d) show the emotional processes of the musician and the emotional resonances of the audience, respectively. In Figs. 5(b), (c) and (d), the smooth waveforms are those for modeling the emotions of the musician and the other ones are those for audience. We can see that the emotions of the audience follow those of the musician with strong correlations though some significant delays and errors exist. Figure 5(e) shows the process of "pay attention". We can see that at first the audience did not focus on the important characteristics of the music (such as classic or not, noise or music). However, after a while he can focus on some characteristics and interpreted the music in his own manner. Figure 5(f) shows the music that the audience "understands", which is reproduced by his own brain. Comparing Figs.5(a) and 5(f) we can see that an almost identical synchronization is achieved. It is a verb equality of "understand".

4 Concluding remarks

As a substantial axiom of any computation framework, the equality is the most important building block for any computation. In classical computations, equality is used as a mental existence, an idealized operation. However, since verb computation itself copes with the mental world of human being, the idealized equality loses its validity. Instead, dynamic verb equalities can reflect the real aspects of the processes which are encoded by verbs such as *feel*, *know*, and *understand*. Verb equalities are dynamic processes, which allow the variety and richness exist in the contexts of different (machine) personalities for modeling the same objects. I believe that these kinds of varieties can introduce machine-personality (*machinality*) into machine intelligence. Although in this paper I use the well-established synchronizing theory of dynamic systems to model verb equality, I am afraid that synchronization is not the only way that the nature uses for coping with this kind of phenomenon.

Based on the understanding of verb equality, we can develop a framework of verb computation. A direct application of this kind of verb computation is the next generation of machine intelligence which should have a core called *machinself* (from machine itself).

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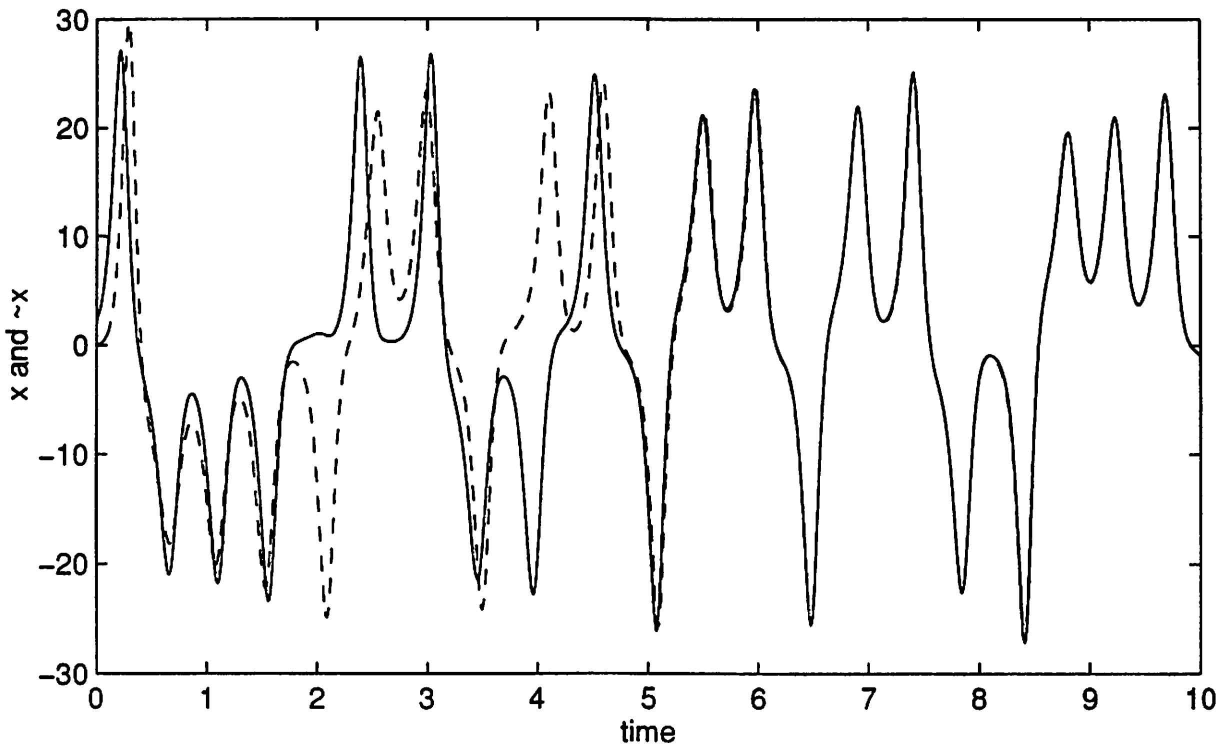
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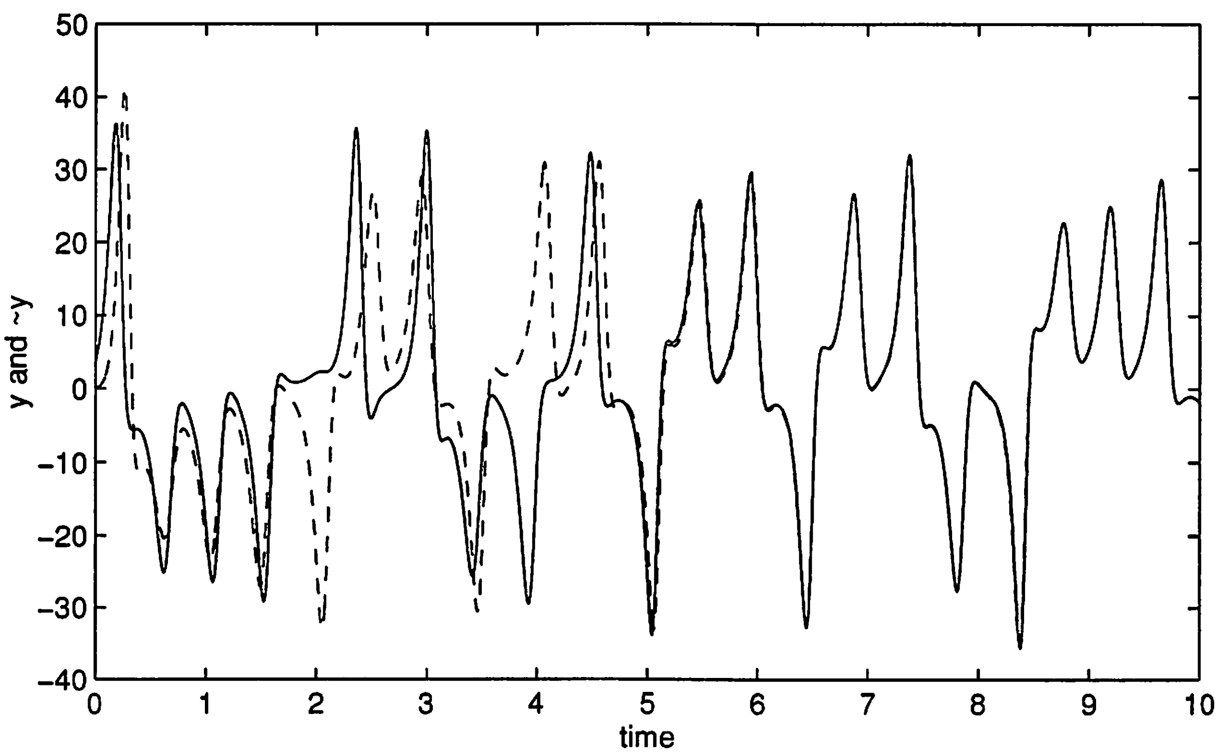
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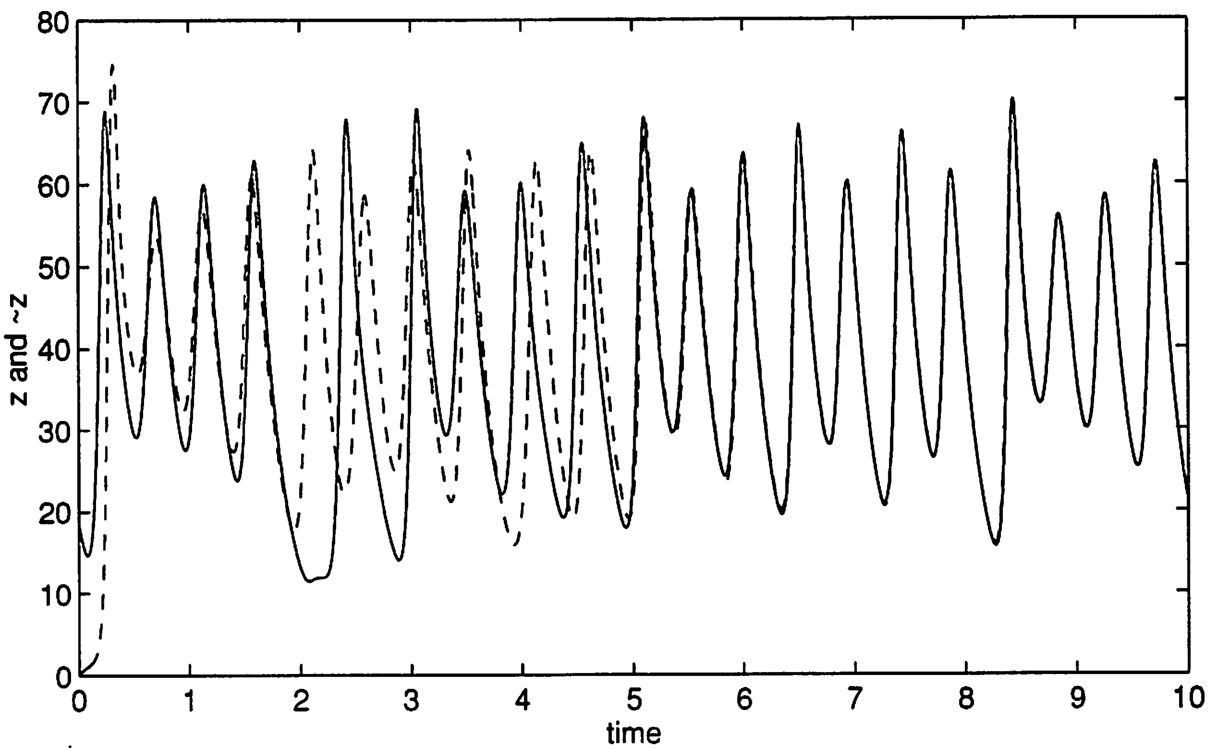
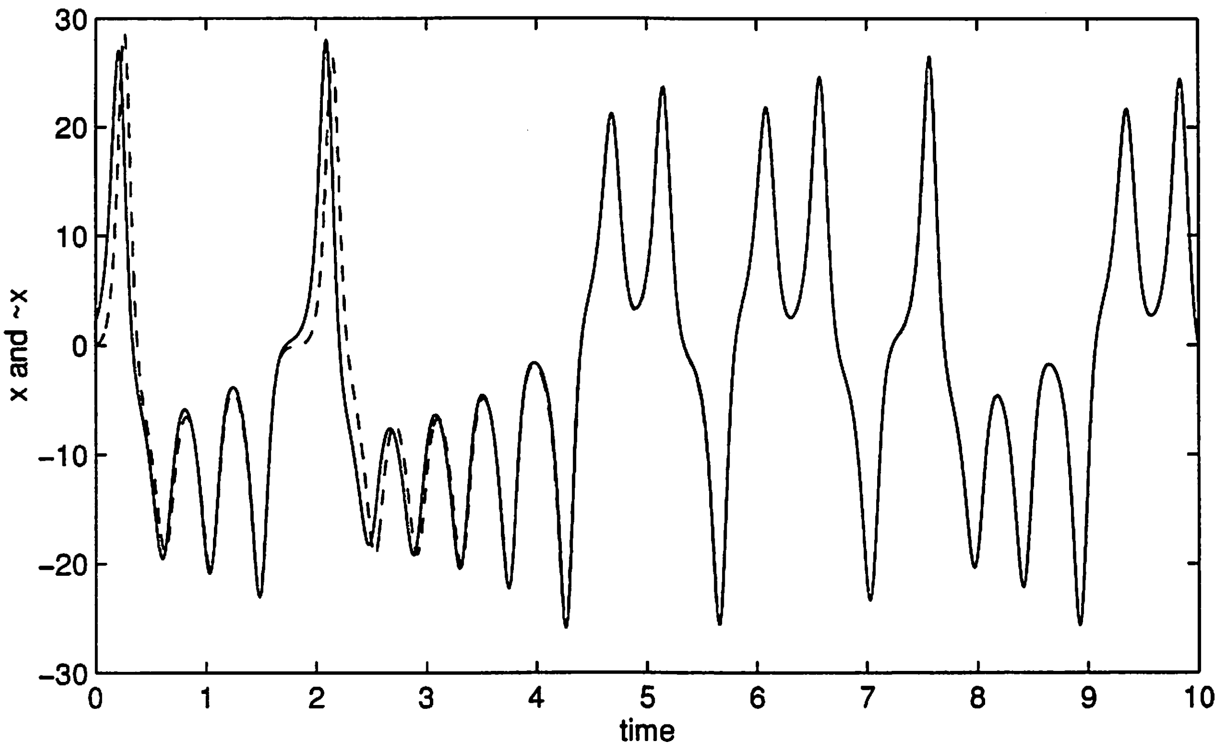


(c)

Figure 1: Identical synchronization of two Lorenz systems as the model of verb equality using mutual coupling. (a) The evolving processes of $x(t)$ and $\tilde{x}(t)$. (b) The evolving processes of $y(t)$ and $\tilde{y}(t)$. (c) The evolving processes of $z(t)$ and $\tilde{z}(t)$.



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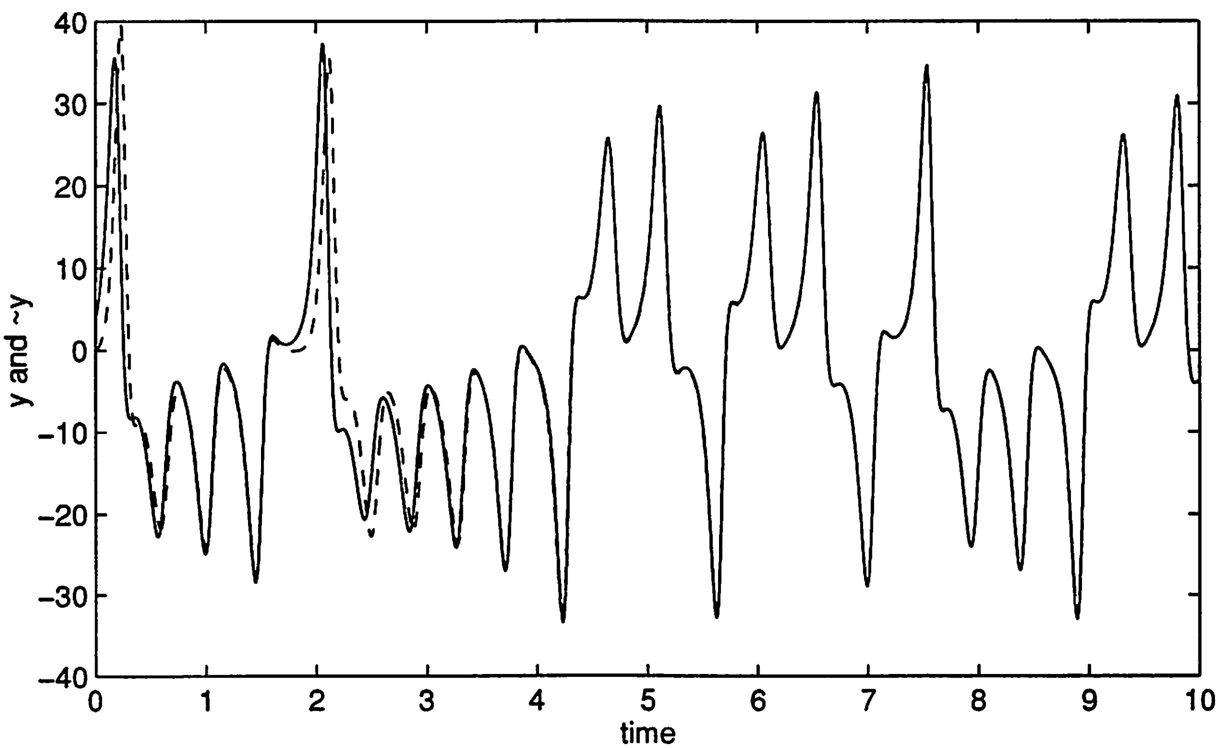

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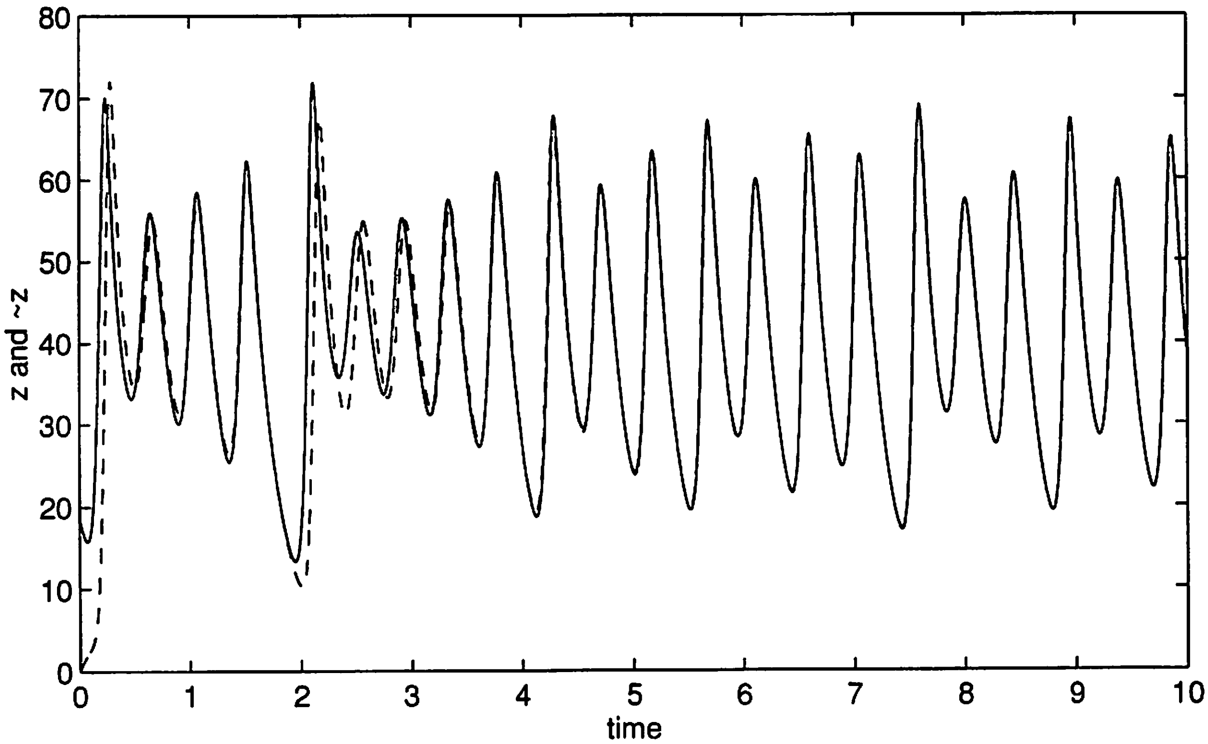
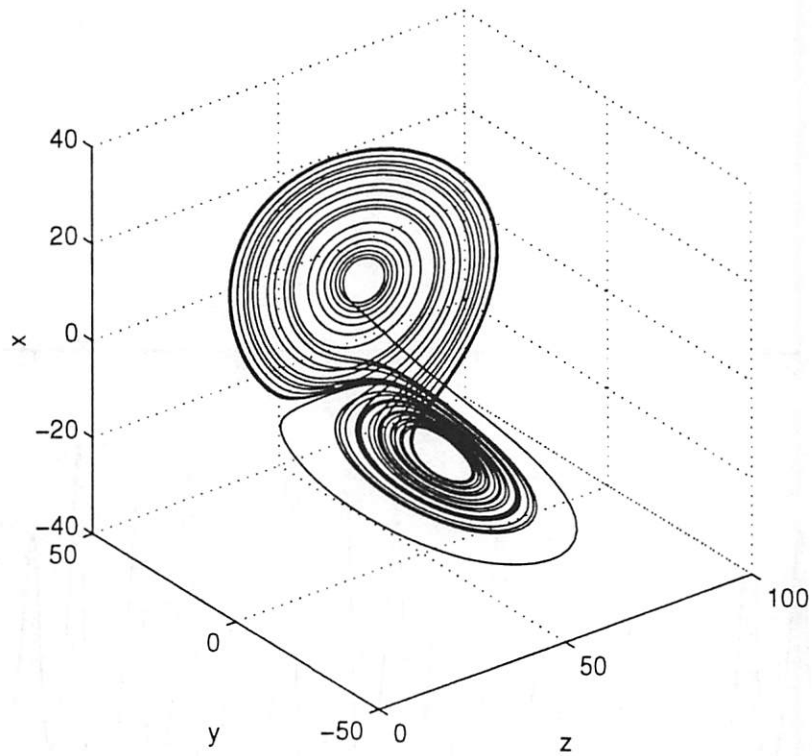
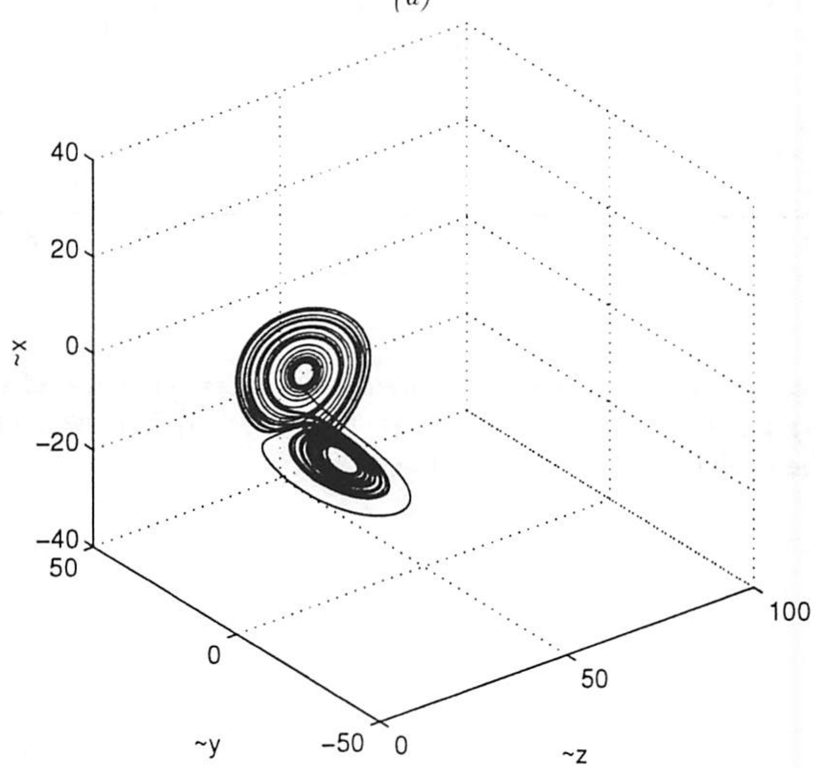


(c)

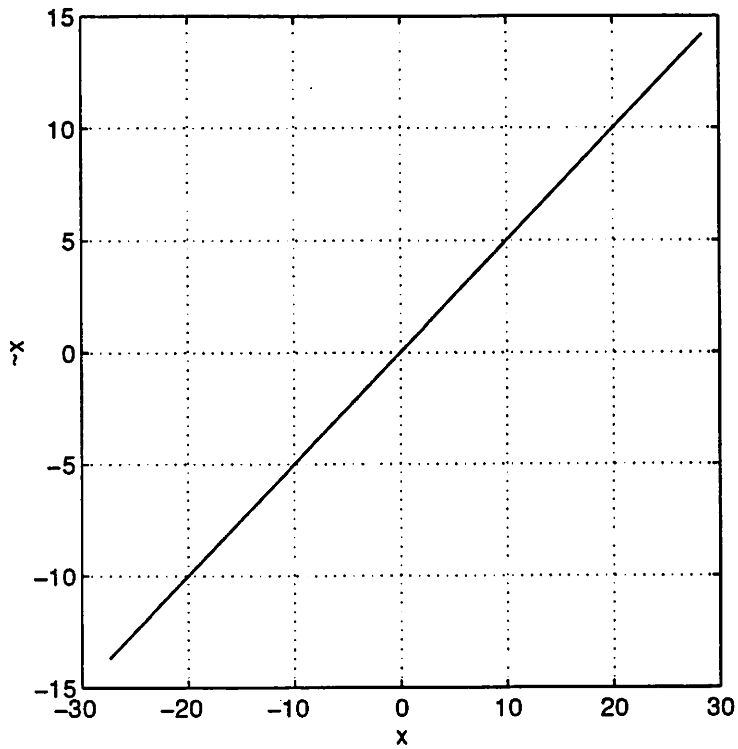
Figure 2: Identical synchronization of two Lorenz systems as the model of verb equality using uni-coupling. (a) The evolving processes of $x(t)$ and $\tilde{x}(t)$. (b) The evolving processes of $y(t)$ and $\tilde{y}(t)$. (c) The evolving processes of $z(t)$ and $\tilde{z}(t)$.



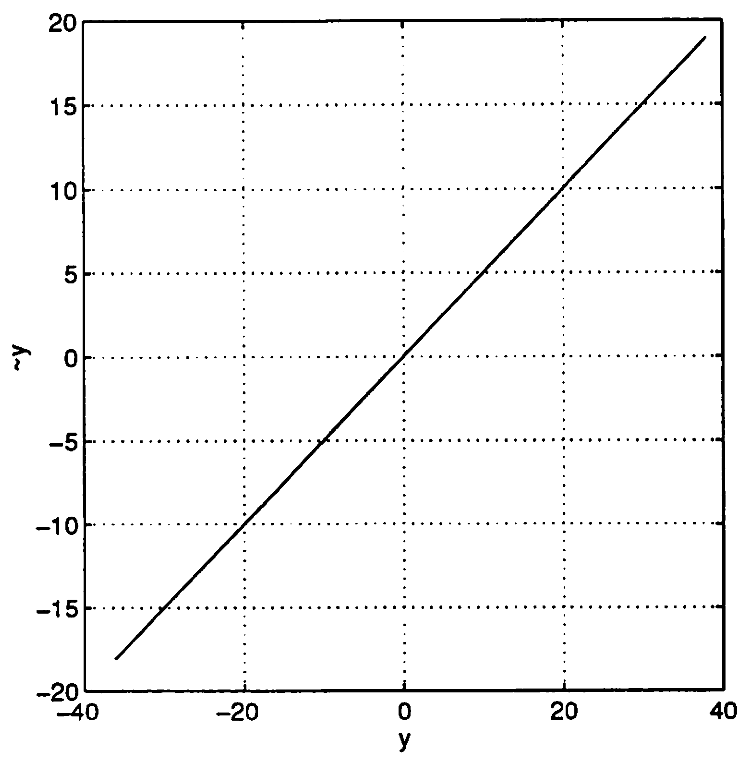
(a)



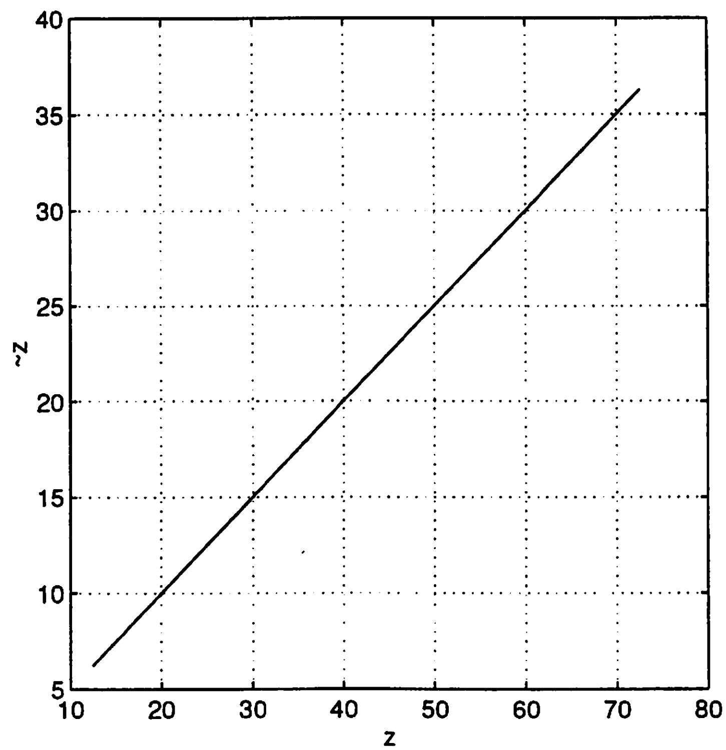
(b)


15
10
5
0
−5
−10
−15
~x
−30
−20
−10
0
10
20
30
x

(c)

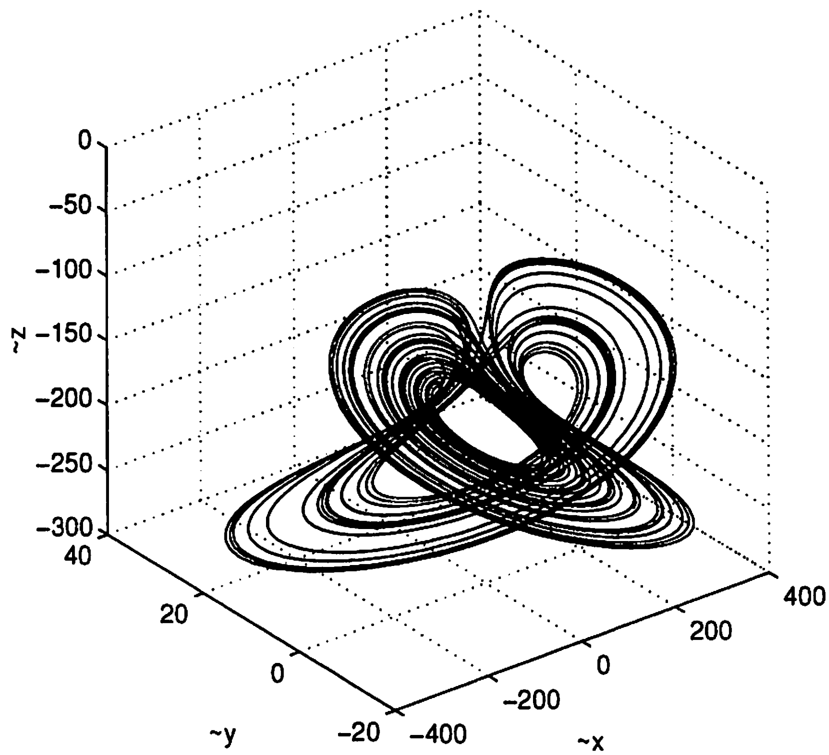

20
15
10
5
0
−5
−10
−15
−20
~y
−40
−20
0
20
40
y

(d)

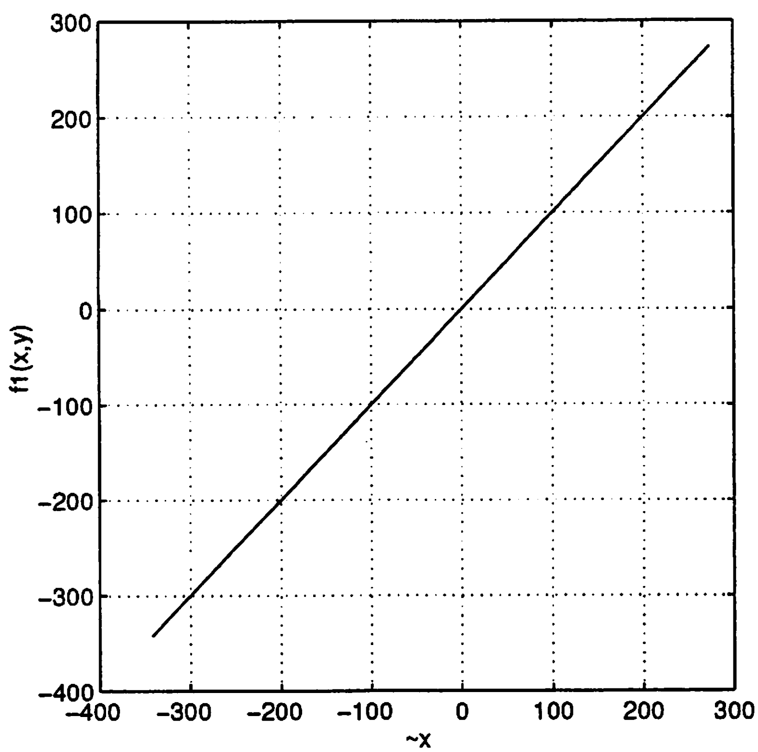


(e)

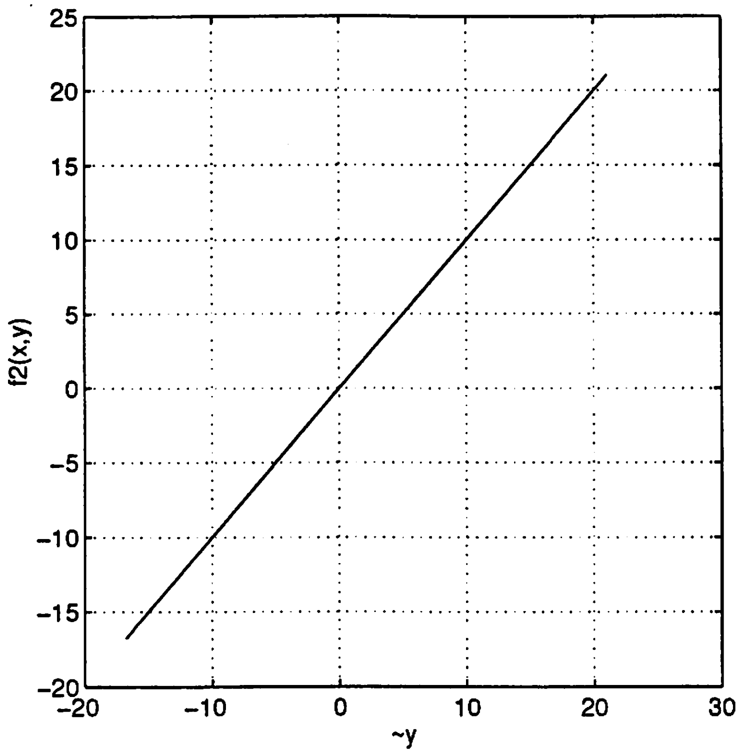
Figure 3: Scaled GS of two Lorenz systems for modeling verb equality with qualitative similarity. (a) The attractor of Verb 1. (b) The attractor of Verb 2. (c) x verse $\tilde{x}$ plot. (d) y verse $\tilde{y}$ plot. (e) z verse $\tilde{z}$ plot.


0
-50
-100
~z -150
-200
-250
-300
40
20
0
-20
~y
-400
-200
0
200
400
~x

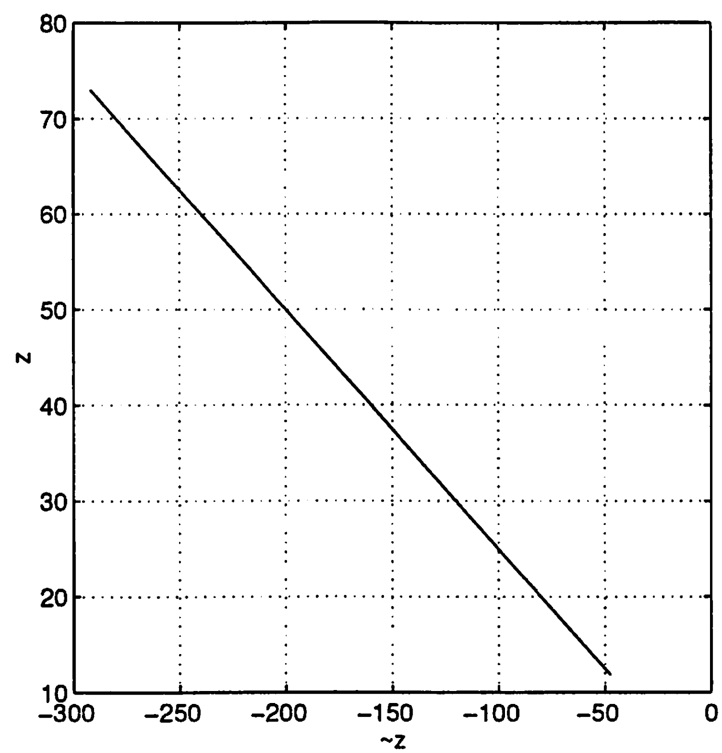
(a)


300
200
100
0
-100
-200
-300
-400
f1(x,y)
-400
-300
-200
-100
0
100
200
300
~x

(b)


25
20
15
10
5
0
−5
−10
−15
−20
f2(x,y)
−20
−10
0
10
20
30
~y

(c)


80
70
60
50
40
30
20
10
z
−300
−250
−200
−150
−100
−50
0
~z

(d)

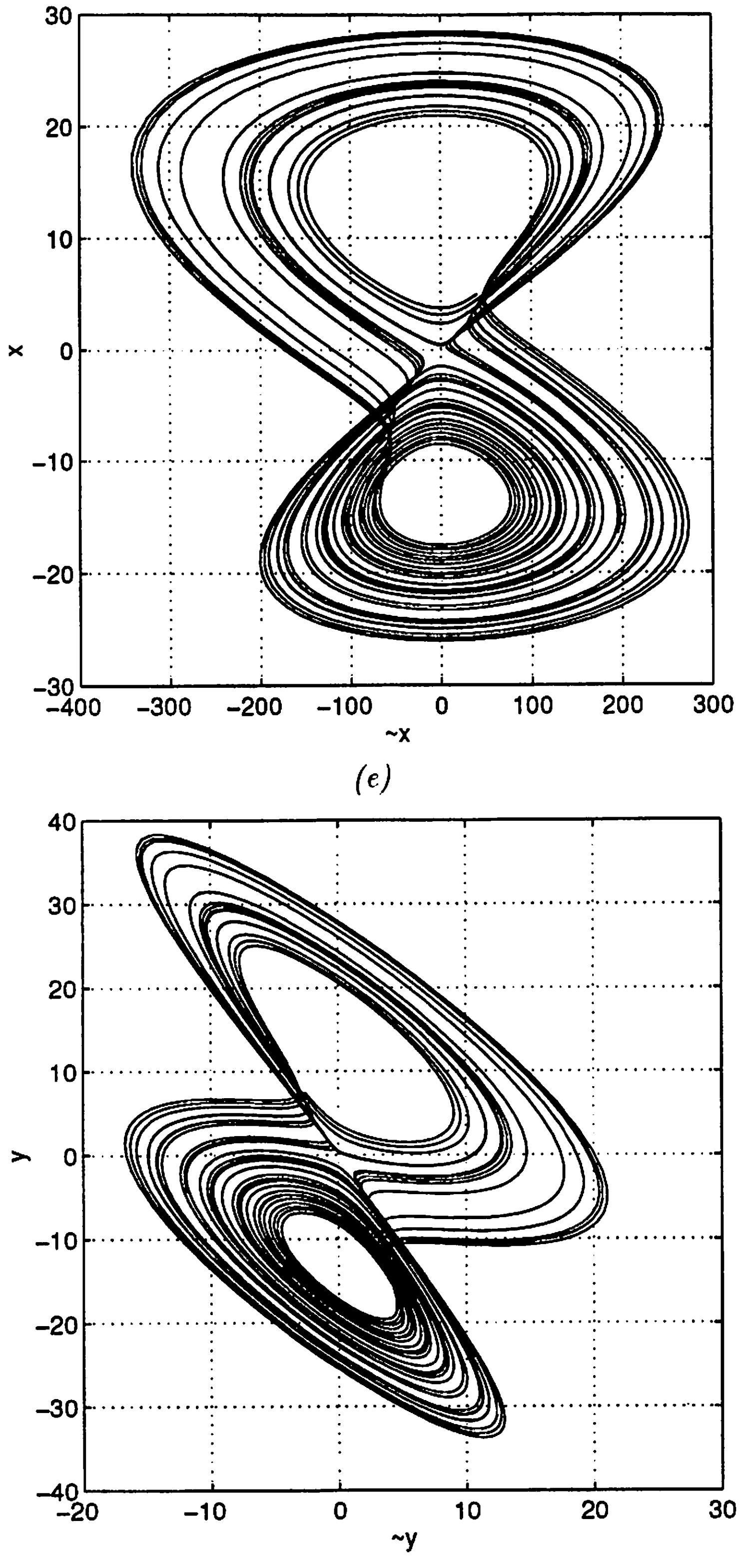
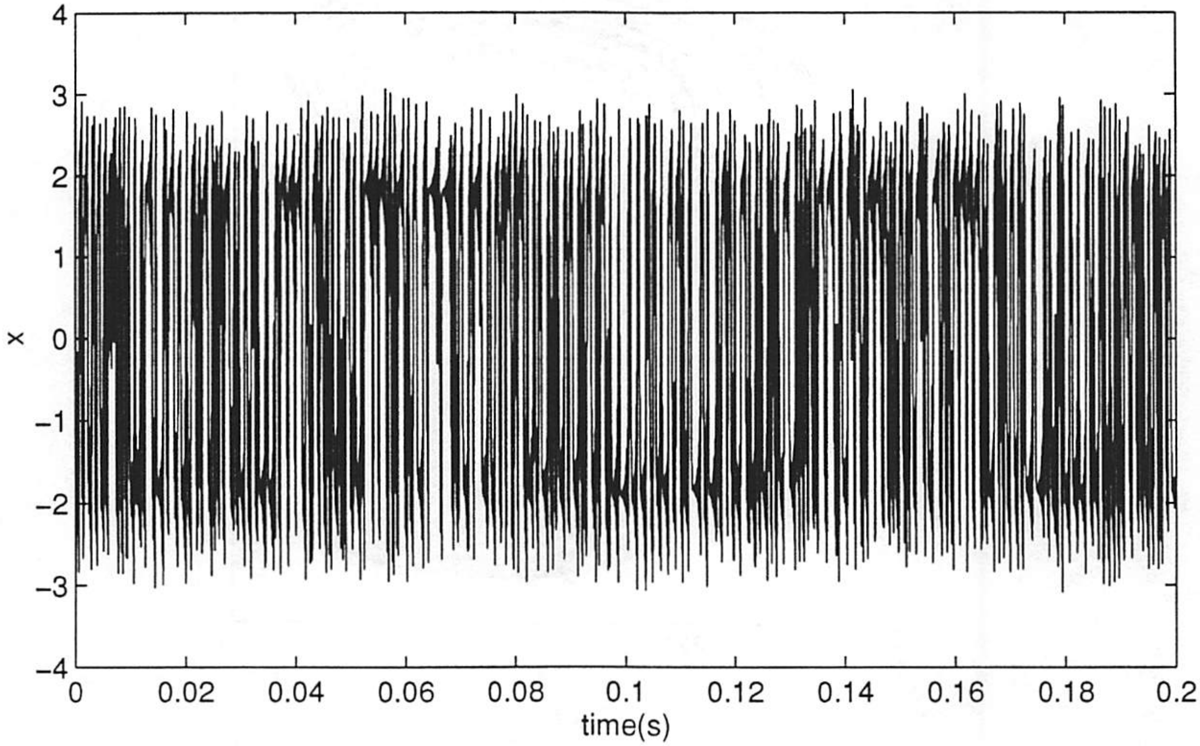
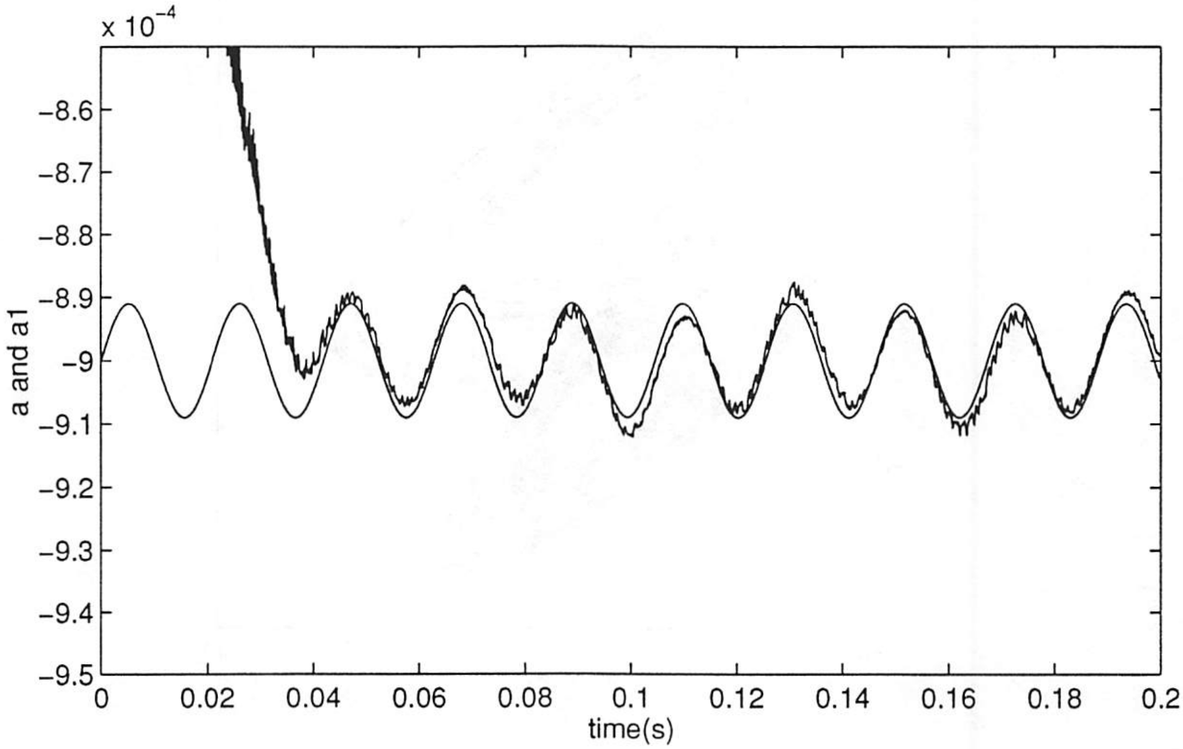


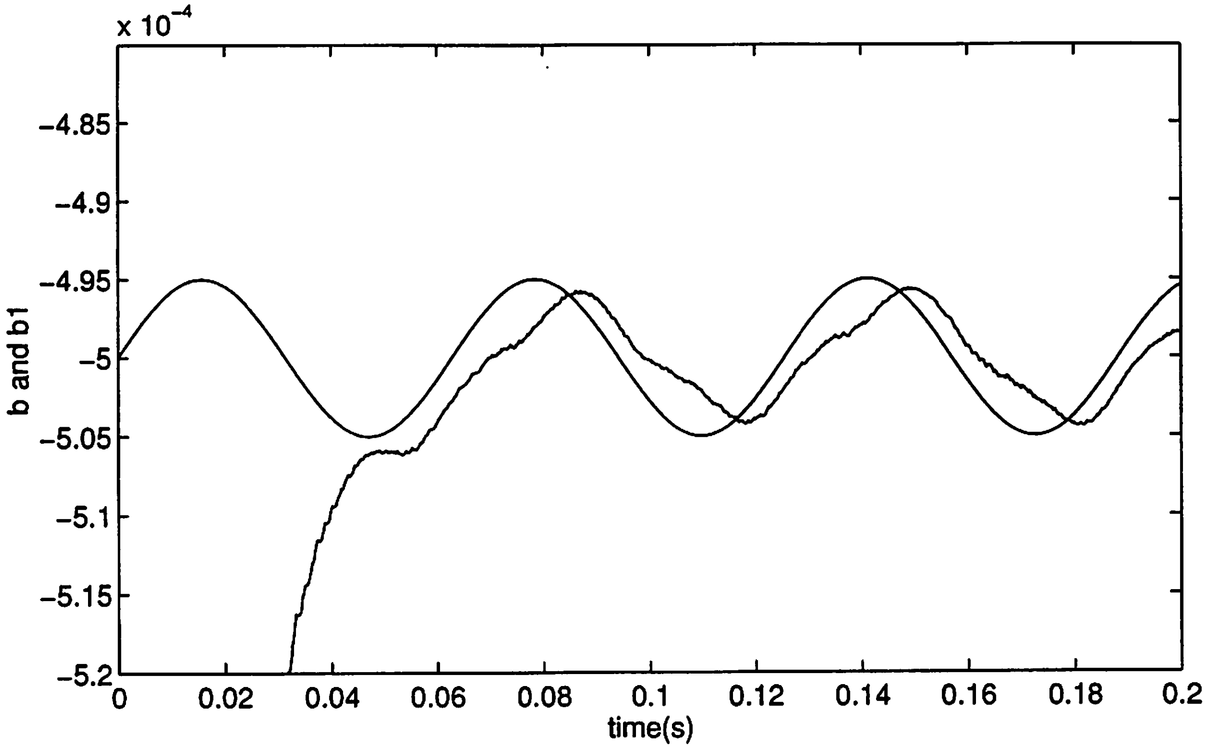
Figure 4: Linear GS of two Lorenz systems for modeling verb equality with linear transformation. (a) The attractor of Verb 2. (b) $\tilde{x}$ verse $f_1(x, y)$ plot. (c) $\tilde{y}$ verse $f_2(x, y)$ plot. (d) $\tilde{z}$ verse z plot. (e) $\tilde{x}$ verse x plot. (f) $\tilde{y}$ verse y plot.



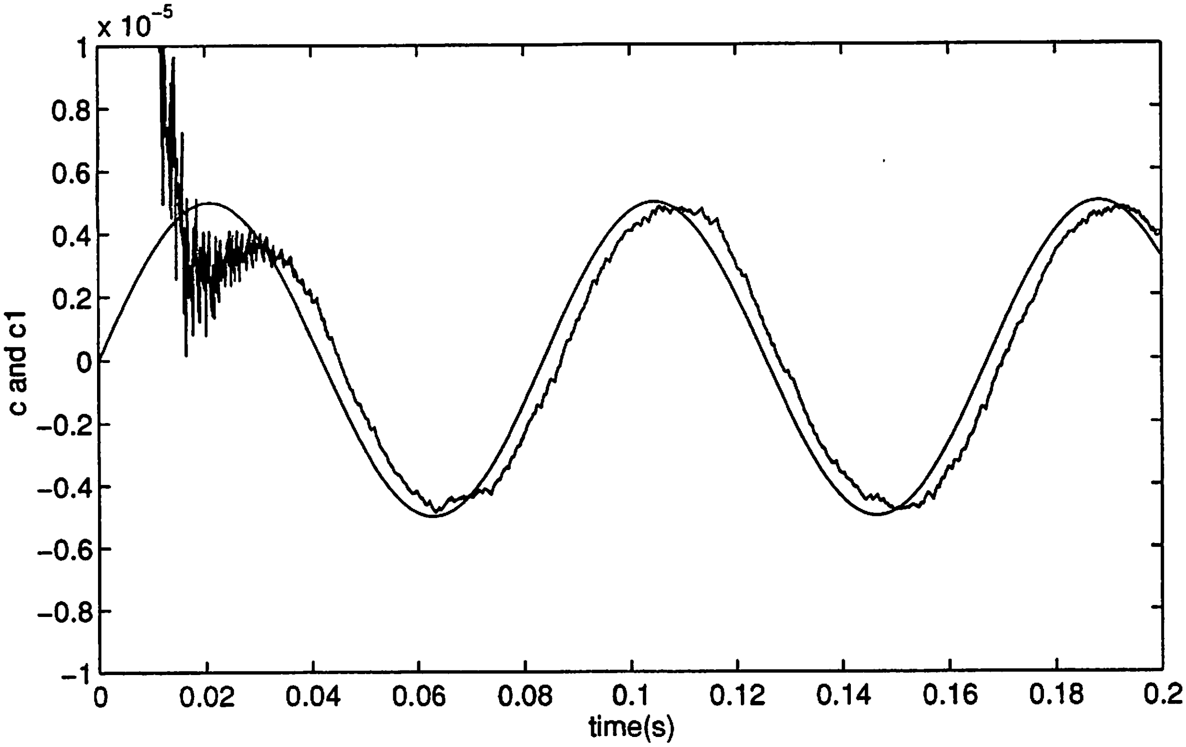
(a)



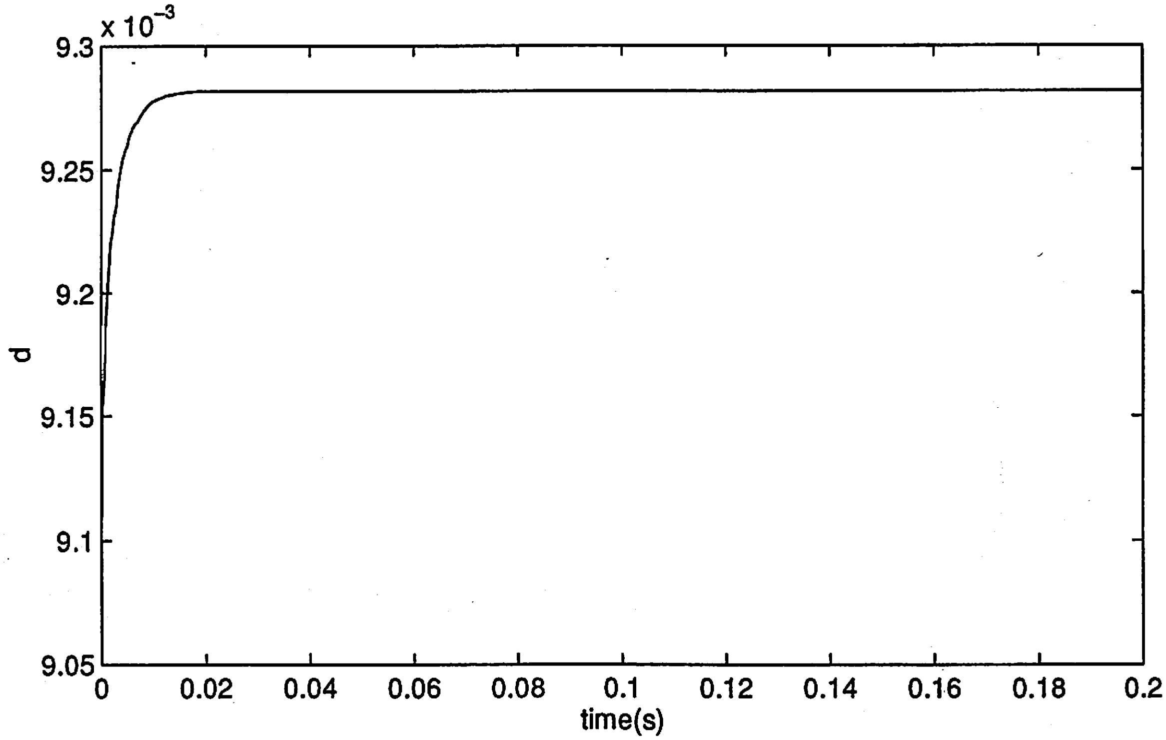
(b)


x 10^-4
-4.85
-4.9
-4.95
-5
-5.05
-5.1
-5.15
-5.2
b and b1
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
time(s)

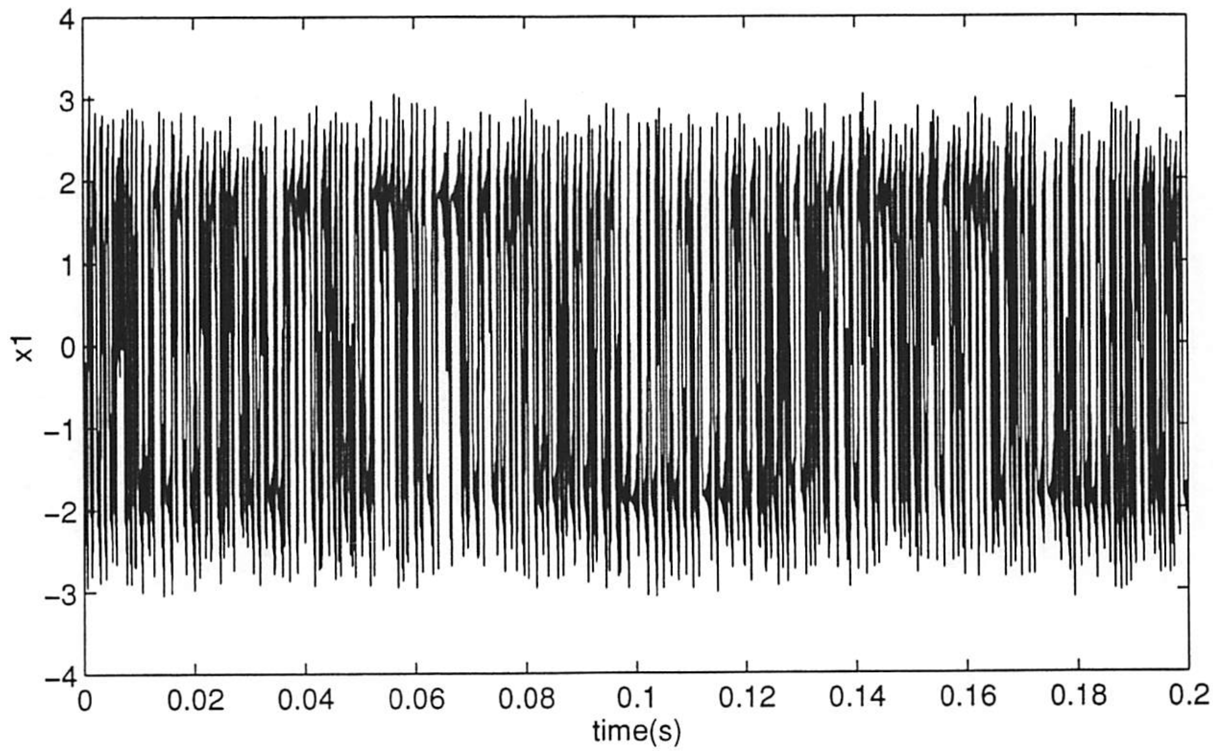
(c)


x 10^-5
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
c and c1
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
time(s)

(d)


x 10^-3
9.3
9.25
9.2
9.15
9.1
9.05
d
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
time(s)

(e)



(f)

Figure 5: The "understand music" process. (a) The music waveform embedded different emotions and feelings of the musician. (b) The time-varying property of $a(t)$ and the emotional resonance of $a_1(t)$. (c) The time-varying property of $b(t)$ and the emotional resonance of $b_1(t)$. (d) The time-varying property of $c(t)$ and the emotional resonance of $c_1(t)$. (e) The "pay attention" process. (f) The evolution process of what the audience "understands".