A Study of Adverbs as Modifiers of Computational Verbs

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***Abstract*— From linguistic point of view, adverbs are modifiers of verbs. In computational verb theory, adverbs are modeled as mathematical operators acting upon computational verbs. The relations between verbs and adverbs can result in many kinds of mathematical operators in different contexts. In this paper, the adverb "`as well as`" was modeled as modifiers of computational verbs and its effects of modifying the evolving functions of computational verbs were studied.** *Copyright © 2008 Yang's Scientific Research Institute, LLC. All rights reserved.*

***Index Terms*— Computational verb, root verb, verb distance**

I. Introduction

ADVERBS can be used to modify adjectives and verbs. There are only a few adverbs of degree can be used to modify adjective while all adverbs can be used directly or indirectly to modify verbs. In this paper, we will study the modifying effects of adverb `as well as` on verbs based on computational verb theory, which was invented in the Department of Electrical Engineering and Computer Sciences, University of California at Berkeley in 1997[4], [5].

In computational verb systems, adverbs can be classified into two classes [1]. Adverbs in the first class can be explicitly represented by modifying function with clear physical meanings; namely, the *time-adverbs* and *place-adverbs*. The adverbs in the second class are concerned with perception called *perception-adverbs*. In this paper, we will study the effects of perception-adverbs on computational verbs.

The organization of this paper is as follows. In Section II the root computational verbs will be presented. In Section III the modifying effects of adverbs on root computational verbs will be modeled.

II. Root Computational Verbs

Since every computational verb is a dynamical system, the way that an adverb interact with a computational verb is rather complex. In this paper, we only study the relation between adverbs and the simplest computational verbs called *root (computational) verb*. Modifying root verbs by using adverbs, we can construct many other computational verbs. In this paper, we construct the following three root verbs: "increase", "decrease" and "stay", of which the evolving functions are given by:

$$\textit{decrease}: \quad \mathcal{E}_d(t) = x_0(1-e^{-kt}) + b, t \in [0,\infty); \quad (1)$$

$$\textit{increase}: \quad \mathcal{E}_i(t) = x_0 e^{-kt} + b, t \in [0,\infty); \quad (2)$$

$$\textit{keep}: \quad \mathcal{E}_k = x_0 + b, t \in [0,\infty). \quad (3)$$

Figure 1 shows the evolving functions of root verbs. In Fig. 1, the evolving functions of computational verbs increase, decrease and keep are show as red, green and blue curves, respectively. Observe that we assume exponential changes for both increase and decrease.

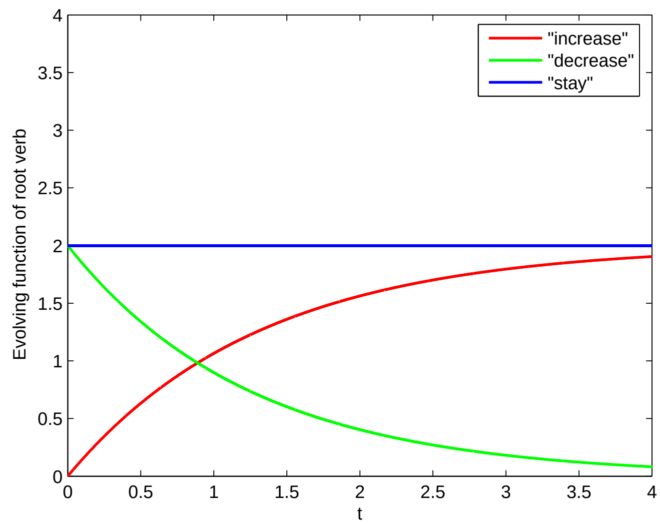

Fig. 1: Evolving functions of root verbs in Eqs. (1), (2) and (3). The parameters are $x_0 = 2$, $k = 0.76$ and $b = 0$.

III. Adverbs and Their Modifying Effects

Since adverbs are used to modify verbs, we can define an adverb as a general operator on the evolving systems of computational verbs. Given an adverb β, which is used to modify a computational verb α, the modified verb can be represented as $\beta \circ \alpha$ [1].

An adverb can be concerned with *time*, *place*, and *perception*. Here we study two *perception-adverbs* "`fast`" and "`slowly`", which modify the root verbs "increase" and "decrease" to generate new computational verbs such as `fast` ∘ increase and `slowly` ∘ increase.

In Fig. 2 we show three examples of "increase" with different values of parameter k. The values of k for the red, green and blue curves are 0.76, 2 and 5, respectively. Observe that the parameter "k" can change the increasing speed of "increase". An increase in"k" increases the increasing speed

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of "increase". In this sense, the parameter "k" plays a role of a modifying operator of computational verbs.

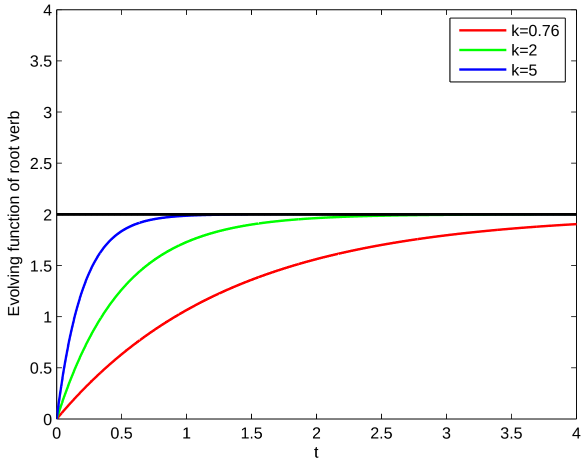


Fig. 2: The effect of the parameter "k" on root verb "increase". The parameters are $x_0 = 2$, $b = 0$ and $k = 0.76, k = 2, k = 5$.

IV. Modeling the Effects of Adverbs

We use three typical adverbs/adverbials, "fast", "slowly" and "fast as well as slowly", when we talk about the speed of "increase" or "decrease". All these adverbs are concerned with perceptions. In most cases, we need contexts, which provide additional conditions, to judge whether it "increases" "fast","slowly" or "fast as well as slowly". However, sometimes the contexts are not necessary.

A. Without Contexts

1) Two Examples:

Example 1. When we have to choose a number, which is big as well as small from the interval $[0, 1]$. Most of us are most likely to choose "0.5" as the answer.

Example 2. Let's take a look at Figs. 3(a) and 3(b). Most of us may strongly think that the adverb "fast as well as slowly" is the best choice to describe the verb "increase" and "decrease" shown in Fig. 3.

Remark. We find that people often choose medium values when they express "as well as". For example, the value "0.5" is the medium value between the two extremes "0","1" in Example 1. While "$\pi/4$" is the medium value between the two extremes *x-axis, y-axis* and *y=3, y-axis* in Example 2.

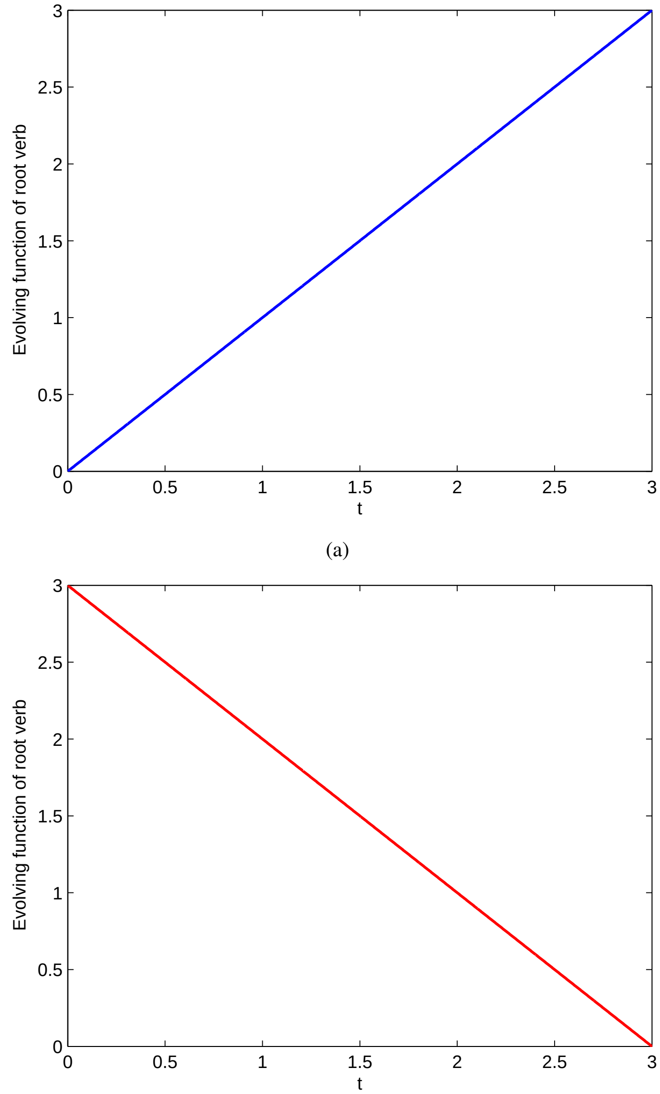
2) Modeling:

Definition 1. [2] *The partial distance between two computational verbs* V_1 *and* V_2 *is given by:*

$$d(\mathcal{E}_1, \mathcal{E}_2)|_{T_1} = \frac{\int_{t_0}^{t_1} |\mathcal{E}_1 - \mathcal{E}_2| \,\mathrm{d}t}{T_1} \quad (4)$$

The partial similarity between two computational verbs V_1 *and* V_2 *is given by:*

$$s(\mathcal{E}_1, \mathcal{E}_2)|_{T_1} = 1 - d(\mathcal{E}_1, \mathcal{E}_2)|_{T_1} \quad (5)$$



(a)

(b)

Fig. 3: "increase/ decrease fast as well as slowly"

where $T_1 = t_1 - t_0$,*which is the time set when* $\mathcal{E}_1, \mathcal{E}_2$ *are both defined;* $\mathcal{E}_1$ *and* $\mathcal{E}_2$ *are the evolving functions of* V_1 *and* V_2 *respectively.*

For root verb "increase", let $x_0 = 2, b = 0$, so its evolving function is:

$$\mathcal{E}_1 = 2(1 - e^{-kt}) \quad (6)$$

The linguistic meaning of "increase" in Eq. (6) can be

It exponentially **increases** from 0 to approach 2.

How can we model that the root verb "increase" increase fast as well as slowly without contexts? An idea can be enlightened by the examples. Take the computational verb V_2 shown in Fig. 3(a) as a *template computational verb* [3] and let "k" be a variable to minimize $d(\mathcal{E}_1(t), \mathcal{E}_2(t))|_{T_1}$ ($\mathcal{E}_1(t) = t, T_1 = 2 - 0 = 2$).

To easy the calculation of $d(\mathcal{E}_1(t), \mathcal{E}_2(t))|_{T_1}$ for computer, we use the following formula in discrete-time cases corresponding to Eq. (4):

$$d(\mathcal{E}_1, \mathcal{E}_2)|_{T_1} = \frac{1}{n}\sum_{k=1}^{n} |\mathcal{E}_1(k) - \mathcal{E}_2(k)| \tag{7}$$

Then we get the parameter $k = 0.76$, the corresponding evolving function is:

$$\mathcal{E}_1 = 2(1 - e^{-0.76\,t}) \tag{8}$$

The linguistic meaning of "increase" in Eq. (8) can be

It exponentially **increase** from 0 to approach 2 **fast as well as slowly**.

When $0 < k < 0.76$, the linguistic meaning can be

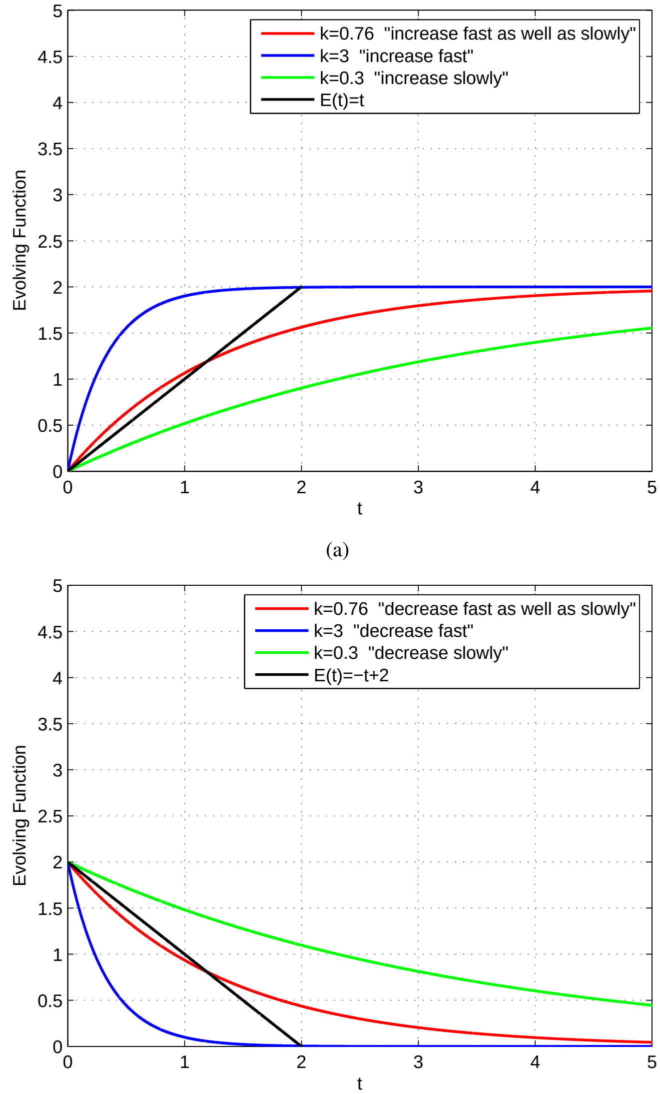
It exponentially **increases** from 0 to approach 2 **slowly**.

When $k > 0.76$, the linguistic meaning can be

It exponentially **increases** from 0 to approach 2 **fast**.

Figure 4 shows root verbs "increase", "decrease" modified by the operator "k". We observed that the results much fit our intuition. "k" is definitely playing the role of a modifier.

For different x_0, we have corresponding verbs evolving "fast as well as slowly". All of them form a computational verb set. And Fig. 5(a) and Fig. 5(b) show the computational verb set {increase fast as well as slowly to approach x_0} and {decrease fast as well as slowly to approach x_0} respectively.



(a) (b)

Fig. 4: The root verbs: "increase/ decrease fast", "increase/ decrease fast as well as slowly", "increase/ decrease slowly". The parameters are $x_0 = 2$, $b = 0$ and $k = 0.76, k = 3, k = 0.3$.

B. Given contexts

In our daily life, contexts always provide additional conditions for us to percept actions in different degrees. Take Example 2. for example, if you're told that "0.6" is big, the answer will not be "0.5".

Example 3. When you drive on a freeway, 60km/h is slow while 120 km/h is fast. So $(60 + 120)/2 = 90$ km/h may be perfect for it's not fast or slow; However, when you drive in a main street of the city, 10 km/h is slow while 40 km/h is fast. So $(10 + 40)/2 = 25$ km/h may be perfect.

If we know that the verb V_1 means "increase fast" while V_2 means "increase slowly", then what will the verb V_3 meaning "increase fast as well as slowly" be? An idea can also be enlightened by Example 3.. In the whole process of "increase", the value of $\mathcal{E}_3$ keeps being the medium value of $\mathcal{E}_1$ and $\mathcal{E}_3$. Namely, their evolving functions satisfy:

$$s(\mathcal{E}_1, \mathcal{E}_3) = s(\mathcal{E}_2, \mathcal{E}_3) \tag{9}$$

1) Linear evolving functions: Let's assume that the evolving functions of V_1, V_2, V_3 are linear functions of life span $[0, \infty)$.

$$\textit{increase fast}: \quad \mathcal{E}_1(t) = k_1 t,\ t \in [0, \infty) \tag{10}$$

$$\textit{increase slowly}: \quad \mathcal{E}_2(t) = k_2 t,\ t \in [0, \infty) \tag{11}$$

In this case to satisfy Eq. 9, we find it funny that the only condition is that the operator "k_3" satisfies $k_3 = (k_1 + k_2)/2$.

When $k_3 < k < k_1$, the linguistic meaning of "increase" can be

It linearly **increases fast**.

When $k_2 < k < k_3$, the linguistic meaning can be

It linearly **increases slowly**.

When $k = 0.76$, The linguistic meaning can be

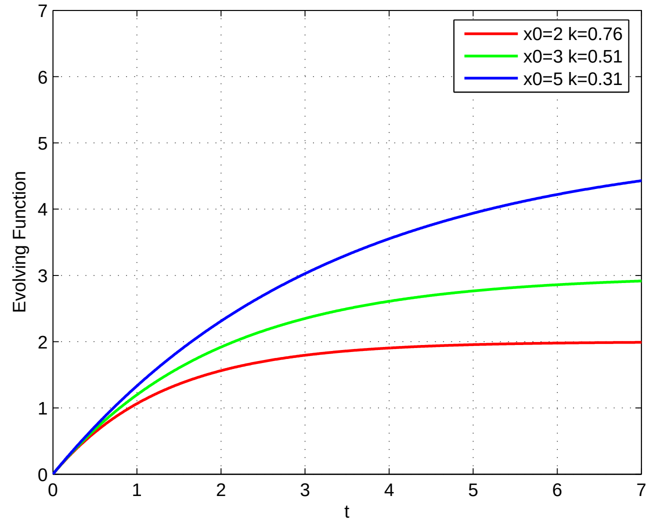
It linearly **increase fast as well as slowly**.

Let $k_1 = 0.577, k_2 = 1.732, k_3 = (0.577 + 1.732)/2 = 1.155$, Fig. 6 shows the result.

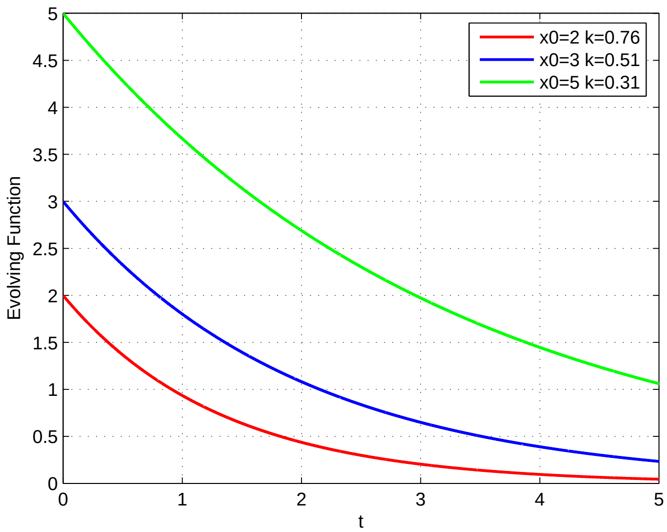
2) Nonlinear evolving functions: Let's assume that the evolving functions of V_1, V_2, V_3 are nonlinear functions of life span $[0, \infty)$.

$$\textit{decrease fast}: \quad \mathcal{E}_1(t) = x_1(1 - e^{-k_1 t}),\ t \in [0, \infty) \tag{12}$$

$$\textit{increase slowly}: \quad \mathcal{E}_2(t) = x_2(1 - e^{-k_2 t}),\ t \in [0, \infty) \tag{13}$$



(a)



(b)

Fig. 5: The computational verb set {increase/ decrease fast as well as slowly to approach x_0} .

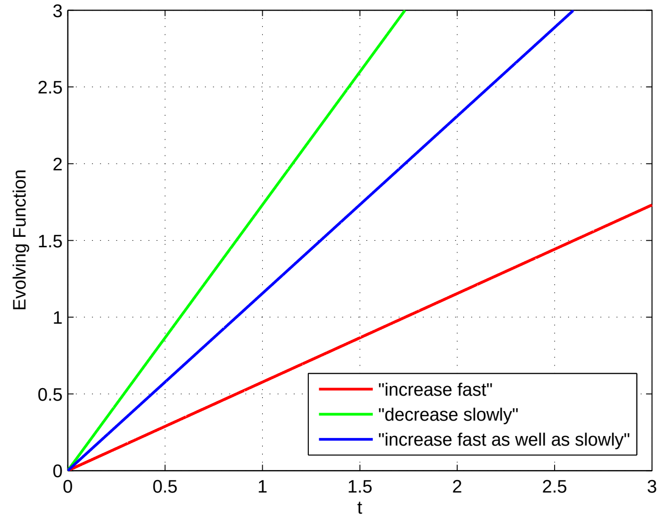


Fig. 6: $\mathcal{E}_1$ and $\mathcal{E}_2$ are linear functions

In this case, it's difficult to keep the value of $\mathcal{E}_3$ being the medium value of $\mathcal{E}_1$ and $\mathcal{E}_3$ accurately in the whole evolving process. But we can find out a "k_3" satisfying Eq. 9 to keep it evolving "fast as well as slowly" in general trend.

A. if $\mathbf{x_1 = x_2}$. Let $x_1 = x_2 = 2, k_1 = 2, k_2 = 0.5$, to satisfy Eq. 9, we get $k = 0.800$, $x_3 = 2$. *Warning:* When we calculate the similarity, T_1 defined in Eq. 4 should be big enough to make the verbs almost approach x_1, x_2 and x_3 respectively. Fig. 7 shows the result.

So when $k = 0.800$, the linguistic meaning can be

It exponentially **increase** from 0 to approach 2 **fast as well as slowly**.

When $0.5 < k < 0.800$, The linguistic meaning can be

It exponentially **increases** from 0 to approach 2 **slowly**.

When $0.800 < k < 2$, The linguistic meaning can be

It exponentially **increases** from 0 to approach 2 **fast**.

B. if $\mathbf{x_1 \neq x_2}$. Because V_1 and V_2 "increase" to approach x_1 and x_2 respectively, V_3 should approach $(x_1 + x_2)/2$ at last, namely, $x_3 = (x_1 + x_2)/2$. Then we also can find a specified "k" to satisfy Eq. 9. T_1 should be also big enough as it mentioned before.

Let $x_1 = 4, x_2 = 2, k_1 = 0.5, k_2 = 1$, we get $k_3 = 0.6, x_3 = (4+2)/2 = 3$. Fig. 8 shows the result. In this case, it's hard to judge whether it increases fast or slowly only by "k" or "x_0".

V. CONCLUSIONS

Since adverbs are used to express the variations in the manners and conditions under which verbs indicate actions, they can be viewed as the modifiers of verbs [1]. In human minds, we often judge the degree of the variation of actions by comparing extreme cases, which are given as default or by contexts.

The basic idea is to look for a medium state, which is "evolving fast as well as slowly" in this paper. In fact, the verb V_3 "increase fast as well as slowly" implies strongly that its evolving function should satisfy Eq. 9.

We proved that the parameter "k" in the evolving function of the root verb plays a role of an adverb. The results in this paper suggest that a computational verb contains a lot of linguistic meanings and dynamical information to explore.

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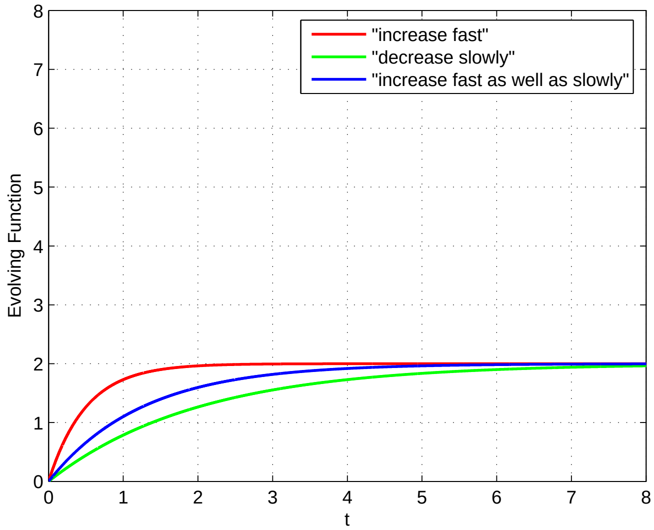

Fig. 7: $\mathcal{E}_1$ and $\mathcal{E}_2$ are nonlinear functions and $x_1 = x_2$.

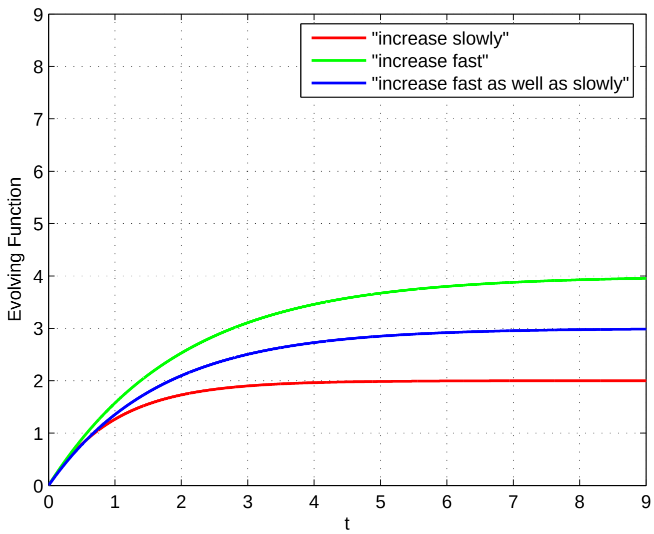

Fig. 8: $\mathcal{E}_1$ and $\mathcal{E}_2$ are nonlinear functions and $x_1 \neq x_2$.

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