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Navigating Language and Terminology in Automatic Control Literature ⋆

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Abstract: Much of our understanding of automatic control relies on descriptions and words. While rooted in mathematical theory, control is generally explained using examples and abstraction. Different terminology is used in different textbooks which can lead to inadvertent miscommunication. Here, the terminology introduced in the most frequently used textbooks is collated. The paper addresses lecturers, students and industrial practitioners alike, who need to communicate, not only for understanding but also when building control systems. The focus is on English terminology of the single control loop and the PID controller. A section is dedicated to the Swedish and German language, highlighting helpful as well as obstructive vocabulary. This article provides an overview to raise awareness and to serve as a basis for discussion. It is not intended to be a complete list of words that should or should not be used.

Keywords: Automatic control terminology, control language, communication, technology transfer, control engineering education.

1. INTRODUCTION

Control engineering is a key technology in many different engineering disciplines and finds its application in the process, automotive, aviation, energy, telecommunication, heating and cooling industry and, more recently, in medical applications. The PID controller is the most successful control strategy that is common to all these industries.

However, the workings of control remains a closed book to the general public, is generally not taught at high school level, and also rarely included in university syllabus outside of engineering disciplines. This is despite the fact that feedback control is not difficult to understand and in fact is a basic principle everyone employs and encounters on a day-to-day basis, e.g. the temperature control mechanism in the human body.

One of the hurdles to overcome is language. The need for communication skills among engineers has been widely recognised (Riemer (2002), Galloway (2007)). It is particularly vital for control engineers, as control engineering is a means to an end and thus embedded in other disciplines, such as chemical or electrical engineering. Communication skills are essential for the engineers working in an interdisciplinary and global environment. In general, by overcoming linguistic confusion and misunderstandings the communication will be easier and the solving of problems more efficient. This applies both to teaching situations as well as to industrial and academic work. But it is not only by knowing the exact terms used in other cultures and linguistic communities that teaching and discussions run smoother. The awareness of different terminology cultures alone may prevent misinterpretation and hopefully facilitate to fill gaps and understand overlaps.

Even more challenging is the importance of communication with non-engineers. This applies to education at a high school level in the same way as it applies to control technology users that are generally not versed in the mathematical background.

There is currently no standard terminology in control engineering, not even within one application such as the process industry. However, there are textbooks that have been influential in the past and other textbooks tend to consult these books for references on terminology.

The purpose of this work is to collate and examine the language used in control engineering. The intention is not to be prescriptive but to highlight the most commonly used terminology and to consolidate expressions, that have found their way into the control vocabulary. By identifying the most common terms, it is up to the reader to choose the relevant terminology for specific applications, hopefully more streamlined than in the past.

The focus is on basic control terminology and PID control terminology. The main language considered in this work is English, as well as the native languages, Swedish and

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German, of the authors. While English is currently the language used in science and engineering around the globe, there is a benefit in teaching complex concepts in one's native language. Also, the control technology user may not be exposed to and/or fluent in English. A discussion of control terminology in other languages is encouraged.

The methodology used in this work is to identify the most commonly used textbooks. We have examined a number of textbooks and put together which book has used which terminology.

Contribution of this paper:

(1) Collating the vocabulary used in the most popular control engineering textbooks (in English, Swedish and German)
(2) Comparing English, Swedish and German terminology
(3) Providing more precise language in PID tuning

The paper is organised as follows. First, the selection of textbooks is motivated and each textbook is briefly introduced. The importance of language and the use of language in engineering disciplines is also briefly discussed. Section 3 gives an overview of the basic control terminology used in the textbooks in the English language, focusing on PID control. This section covers controller tuning terminology, that is generally not clearly defined. Section 4 compiles the basic vocabulary according to books used in many Swedish and Germany university courses, highlighting particularly self-explaining terminology as well as particularly difficult terminology that students generally struggle with.

2. CONTROL ENGINEERING TEXTBOOKS

Here, we introduce the reviewed textbooks used and why. The initial focus is on general control engineering textbooks that are used in undergraduate education as a first introduction to the subject. Textbooks which have been published in several editions and are still widely available are included. The books were first published between the 1960s and 1980s and have been influencing control engineering education over many decades. We first focus on international books that are published in English followed by Swedish and German textbooks. In addition, we include textbooks that focus on PID control. Edited volumes are excluded as they tend to not be used as reference books.

The oldest general textbook currently in its 8th edition is by Nise (Nise (2020)). The first edition was published in 1965. While the book uses many examples of designing a PID controller, it does not define the PID controller in terms of proportional, derivative and integral part but in terms of pole and zero locations (two zeros one pole).

The textbook by Ogata (Ogata (2010)) was first published shortly after the book by Nise in 1970. The fifth edition was published in 2009. The PID controller is again not introduced in a chapter or section but rather as an example of different design methods. Because the focus of the book is in electronic circuits, the PID controller is given in resistors, capacitors and operational amplifiers. It is referred to as the "industrial controller".

A book that originates from the subcontinent is by Nagrath and Gopal (Nagrath and Gopal (2021)), first published in 1988, currently in its seventh edition. It covers both discrete and continuous systems and a wide range of examples from different disciplines. PID control was added in the fifth edition. Some of the naming stems from computer system background, such as command input for reference value.

The book Dorf and Bishop (2022) was first published in 1986 and is currently in its 14th edition, still updated by the original authors. Surprisingly, they do not define the basic terminology of reference value and output generally, but rather adapt the input and output variable for each example. For example, in a blood pressure control system, the reference value is the desired blood pressure, the controller output is the valve setting and the actuator output the vapor. The output is the actual blood pressure.

The book by Kuo and Golnaraghi (Golnaraghi and Kuo (2017)) was first published in 1987. In the tenth edition, Golnaraghi became the first author and the current edition includes many examples using LEGO robots. The section on control design focuses on PD-, PI- and PID control.

The textbook by Franklin et al. (Franklin et al. (2019)) was first published in 1988 an is currently in its eighth edition. The book highlights the PID controller in a separate section as "The Three Term Controller" and includes tuning rules by Ziegler and Nichols.

Three textbooks on PID control have been included that were all published in the 2000s: Åström and Hägglund (2006), Visioli (2006) and Moradi and Johnson (2005). These textbooks are not as frequently used in undergraduate education but were chosen because they are reference books to educators and practitioners alike. The fact that all three textbooks were published within two years points towards the maturity of the technology, possibly also to the realisation that PID control is here to stay.

In Sweden, two textbooks are mainly used in the undergraduate courses in control, Thomas (2016) and Glad and Ljung (2006). Thomas (2016) was first published in 1992 and it is currently in its fifth edition, Glad and Ljung (2006) was first published in 1981 and it is in its fourth edition. Both books cover dynamic systems in time- and frequency domain, and introduce the PID controller in dedicated chapters. Thomas (2016) pays more attention to the practical aspects of the implementation, while Glad and Ljung (2006) takes a more theoretical perspective. The same authors have also written Glad and Ljung (2003), which is used as a reference for advanced control courses at multiple Swedish universities, and hence, their terminology has influenced many Swedish control engineers.

In Germany, there are three textbooks that are widely used as a repository for teaching control systems. Föllinger (2022) is a textbook (currently in its 13th edition) first published in 1972 that has been updated orginally by Föllinger and now by four of his former students (Konigorski, Lohmann, Roppenecker and Trachtler). The textbook by Lunze (2014) is currently in its 12th edition, the first edition was published in 1996. The book covers dynamic systems in the time and frequency domain and single loop control design. The third textbook Lutz and Wendt (1995) is called 'Taschenbuch der Regelungstechnik', which translates to 'handbook' or 'manual of practice'

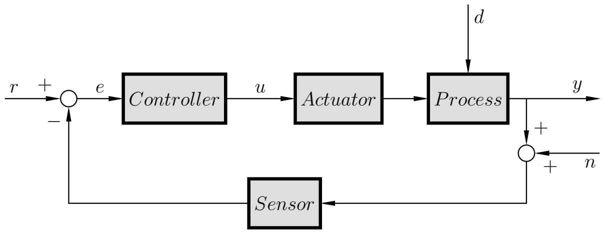

Fig. 1. A simple feed-back loop with reference value r, control error e, control signal u, process output y, load disturbance d, and measurement noise n.

and is 1600 pages long. It strives to provide a complete picture of control engineering and is recommended as a reference book rather than for self-study.

3. CONTROL TERMINOLOGY IN ENGLISH

In this section we discuss the basic terminology used in control that is based on the simple control loop shown in Figure 1, and then focus on the PID control specific terminology. A particular focus is on PID structures as well as the control performance terminology.

3.1 Basic control terminology

In the various textbooks, the simple control loop as shown in Figure 1 comes in many different variations. For example, Nise (2020) does not include the actuator, Franklin et al. (2019) does not include either actuator or sensor. We first focus on the blocks before listing and discussing the different naming given to the signals r, e, u, d, y and n.

Nise (2020) refers to the process as such while giving an alternative – plant. This is the commonly accepted terminology, with sometimes the added word “controlled” so that it becomes ”controlled process”. There are no exceptions to this in the studied literature. The actuator – if mentioned at all – is also called by the same name while the sensor can also be referred to as output transducer (Nise (2020)) or generally feedback elements (Nagrath and Gopal (2021)). The controller is also referred to as controller unit or feedback controller.

While there is general accordance in the terminology of the main function blocks, the signals have alternative, sometimes confusing names. We first list the names before discussing which of the terminology can give rise to confusion. The input to the loop r is referred to as:

- input (Nise)
- reference (Nise, Franklin)
- reference input (Ogata, Kuo)
- reference value (Åström)
- reference signal (Visioli, Johnson)
- setpoint (Ogata, Åström, Johnson)
- command input (Nagrath)

The difference between the reference signal r and the variable that is to be controlled y is referred to as e, which usually stands for error but can also have other names:

- error (Nise, Nagrath, Åström, Kuo)
- actuating signal (Nise)
- actuating error signal (Ogata)
- control error (Visioli)
- process error input to controller (Johnson)
- tracking error (Dorf)

The signal calculated by the controller is denominated by u and can be referred to as:

- control variable (Åström, Visioli)
- manipulated variable (Åström, Visioli)
- controller output (Johnson)
- actuator output to process (Johnson)
- actuating signal (Kuo)

The control objective is to keep the signal y constant or follow a trajectory. y is referred to as:

- output (Nise, Ogata, Franklin, Dorf)
- controlled variable (Nise, Visioli, Kuo)
- controlled output (Nagrath)
- process variable (Åström, Visioli)
- process output (Johnson)

There are at least three examples where a confusion is almost inevitable when

(1) u is referred to the controller output and y referred to as the output. Often, controller output is shortened to output. In fact, in industrial control system, the controller output is generally abbreviated to ‘OP’. Talking about input and output can generally be confusing because in a feedback loop the input to one block is the output of another block.
(2) u is referred to as the control variable and y as the controlled variable. Because both terms are so similar, it is easy to miss the different meaning.
(3) both e and u are referred to the actuating signal. This is an obvious cause for miscommunication but less likely to happen, because e is generally referred to as the error signal.

3.2 PID terminology

One of the many benefits of PID control is that it can be viewed and implemented in the time domain. The control action can be communicated easier to the non-expert users. The time domain definition is given as

$$u(t) = K\left(e(t) + \frac{1}{T_\mathrm{i}}\int e(\tau)\mathrm{d}\tau + T_\mathrm{d}\frac{\mathrm{d}e(t)}{\mathrm{d}t}\right). \qquad (1)$$

In this definition, the parameters that must be set by the user are K, T_i and T_d. Alternatively, the proportional, integral and derivative term can be implemented as follows.

$$u(t) = K_\mathrm{c}e(t) + K_\mathrm{i}\int e(\tau)\mathrm{d}\tau + K_\mathrm{d}\frac{\mathrm{d}e(t)}{\mathrm{d}t} \qquad (2)$$

Here, the tuning parameters are K_c, K_i and K_d. While Eq. (2) seems to be more structured, it is less frequently used, Visioli (2006).

Proportional action is referred to as such and K or K_c is generally called the *proportional gain*. Industrial control systems often use the term *proportional band* (PB), sometimes without defining it. It is hence important to know the relationship, which Åström and Hägglund (2006), Visioli (2006), Moradi and Johnson (2005) give as

$$PB = \frac{100\%}{K}. \qquad (3)$$

This is often used when tuning the controller because it is proportional to the process gain and thus more intuitive to the people who work close to the process.

The integral term in (1) is also called *integral action* or

- automatic reset
- reset control
- floating control
- slow mode

Generally, K_i is the *integral gain* and $T_i = 1/K_i$ is referred to as the *integral time.* In industrial practice, the integral time is also called the *reset time.*

The derivative term in (1), also called *derivative action* or

- anticipatory control
- rate action
- pre-act
- fast mode

Analogue to the integral action, K_d is the *derivative gain* and $T_d = 1/K_d$ is referred to as the *derivative time.*

3.3 PID structures

The definition of a PID controller given in Eq. (1) is the first entry point. There are many adaptations of the original structure to deal with implementation issues and the structure has therefore been adapted in the past. While Eq. (1) is still valid, there are other implementations that are used. Again, confusion is unavoidable, if the terminology is not used correctly. Table 1 lists the different structures as given by Seborg et al. (2019).

3.4 PID control performance

When tuning a PID controller, the correct tuning settings depend on the performance requirements. In this section, we group performance requirement adjectives that are loosely used in textbooks but to our knowledge have so far not been clearly defined. Generally, authors of the textbooks speak of sensitivity, gain and phase margin, and stability. First, the adjectives are collected and then structured.

O'Dwyer (2009) lists and explores many tuning rules. The adjectives used in the book are:

- aggressive
- robust
- slow and fast
- conservative
- acceptable

Often, PID control practitioners responsible for tuning many hundreds if not thousands of PID loops use their own vocabulary. These users often only have access to the time trends of the closed loop behaviour. What will be observed are the reaction to setpoint changes as shown in the right hand plot of Figure 2.

There are many online resources and blogs that discuss PID control performance. One such is controlglobal.com, which focuses on the process industry. In various blogs and articles, the following terminology is used:

- small or large
- slowly damping
- sluggish
- safe
- tight
- moderate
- oscillating
- harsh
- smooth

Most of these words are self-explanatory even to a layperson, such as small or smooth while others require further

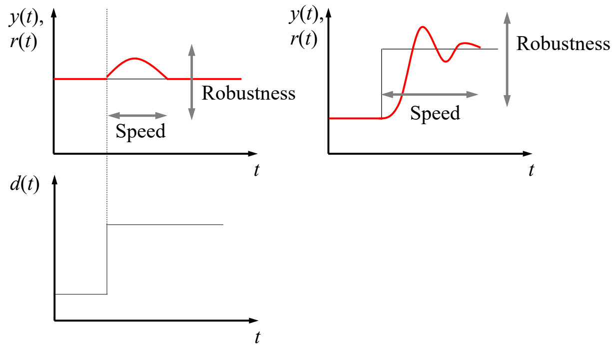

Fig. 2. Left hand plots shows the reaction to a disturbance $d(t)$, right hand plot shows the reaction to a setpoint change $r(t)$. Robustness relates to the amplitude of $y(t)$ and speed of response to the time it takes for $y(t)$ to settle down.

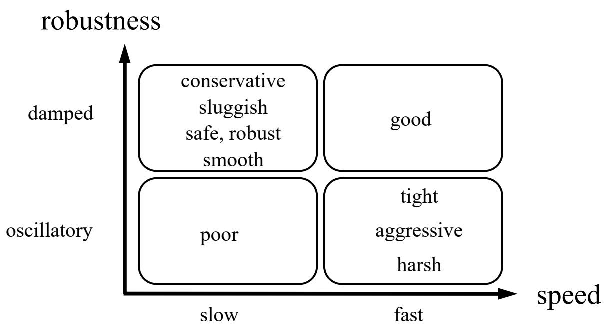

Fig. 3. Tuning adjectives categorised according to robustness and speed. Speed is slow or fast while robustness refers to amplitude and is generally to be understood to be oscillatory or fully damped.

explanations. The basis of these adjectives is the response to disturbances and to setpoint changes as depicted in Figure 2. Here, the deviation of the process output $y(t)$ from the setpoint $r(t)$ is examined. Some vocabulary can be grouped into terms for speed of response only (slow or fast), others in terms of robustness (small or large). However, most adjectives are a combination of both speed and robustness and can be categorised as shown in Figure 3. Robustness is divided into oscillatory and damped responses while speed is categorised into slow and fast responses. In the process industry, PID control performance is generally chosen to be safe or robust. The categorisation given here is not a clear definition but rather a suggestion that can form a basis for discussion and better communication.

4. SWEDISH AND GERMAN TERMINOLOGY

While there is a discrepancy within English vocabulary, further miscommunication can be introduced by translating control terminology into different languages. Here, we focus on Swedish and German vocabulary as used in the mentioned textbooks. The translation is given in Table 2.

The vocabulary that was studied in the Swedish textbooks (Thomas (2016), Glad and Ljung (2003)) is mostly consistent. A bigger difference between the two books is which parts of the control loop in Figure 1 are considered.

Table 1. PID structures as adapted from Seborg et al. (2019)

Name	Alternatives	Transfer function
Parallel	Ideal, additive, ISA form	$K\left(1+\frac{1}{T_i s}+T_d s\right)$
Parallel with derivative filter	Ideal, realisable, ISA standard	$K\left(1+\frac{1}{T_i s}+\frac{T_d s}{\alpha T_d s+1}\right)$
Series	Multiplicative, interacting	$K\left(\frac{T_i s+1}{T_i s}\right)(T_d s+1)$
Series with derivative filter	Physically realisable	$K\left(\frac{T_i s+1}{T_i s}\right)\left(\frac{T_d s+1}{\alpha T_d s+1}\right)$
Expanded	Non-interacting	$K_c+\frac{K_i}{s}+K_d s$
Parallel with weighting	Ideal β, γ	$U(s)=K\left(b\left(R(s)-Y(s)\right)+\frac{1}{T_i s}E(s)+T_d s(c\left(R(s)-Y(s)\right))\right)$

Thomas (2016) treats sensor and actuator as separate blocks, as in Figure 1. In Glad and Ljung (2006) however, the blocks for sensors or actuators are omitted in the corresponding block diagrams. This gives engineers graduating from different universities different vocabulary and understanding of what a control loop is and contains. The difference in the block diagrams also introduce some of the differences in terminology, especially for y. It is called 'mätsignal' in Glad and Ljung (2006), meaning 'measurement signal'. This becomes inconsistent with the block diagram in Figure 1 and Thomas (2016), that includes the sensor. The measurement has not taken place yet where y is marked, and it is instead called 'ärvärde' ('the value that is').

The Swedish vocabulary also contains the word 'utsignal', meaning 'output signal'. This is, in the same way as was highlighted in section 3 for the English 'output', bound to cause confusion. In the Swedish textbooks it is used for y, while in industrial control systems in Swedish it is rather used for u, as the below real life example demonstrates.

– My first terminology related misunderstanding was when I was working with an experienced operator to perform step response experiments at the Aitik concentrator plant. We did not get off to a good start as a lot of vital details were "lost in translation" at the first. The biggest part of the confusion originated from us using the therm 'utsignal', Swedish for 'output signal', for different things. For me, this meant the output signal from the process, while he was talking about the output signal from the controller. As we discovered this, we took a step back and agreed on a shared terminology, after which the discussions made much more sense to both of us. - Frida Norlund

When it comes to PID-termonoligy, Thomas (2016) introduces the PID controller according to (2), while Glad and Ljung (2006) introduces the PID controller as in (1).

In German control system language, there are examples of self-explaining terminology while other words are bound to confuse. The vocabulary is given in Table 2 and identical for all textbooks studied, namely Föllinger (2022), Lunze (2014), Lutz and Wendt (1995). For example, the reference can be referred to as 'Sollwert' or 'desired value' while the process output is the 'Istwert' or 'actual value'. This is helpful, because we compare the actual with the desired value to form the control error.

There are, in fact, two words for reference input: 'Sollwert' and 'Führungsgröße'. While 'Führungsgröße' is the exact translation of reference, 'Sollwert' is the current value of the reference signal. In some cases, though, 'Sollwert' is only used when referring to a constant reference and 'Führungsgröße' otherwise. The same applies to the process output, which can be translated to generally 'Regelgröße' while the current value is 'Istwert'.

A common source of confusion is the manipulated variable which is called 'Stellgröße'. 'Stellen' in German is generally understood as 'to put'. This makes little sense in the control loop: what do you put where? The reason to call it 'Stellgröße' is the abbreviated from the word 'einstellen' which means manipulate or adjust. Manipulated variable should in fact be called 'Einstellgröße'. Leaving out the prefix leads to unnecessary confusion when encountering control for the first time.

Control systems developed in Germany independently during World War II and in the decades thereafter. The control community in Germany was and continues to be large and vibrant. There are estimated to be roughly 100 control institutes at German universities. This is reflected in words such as 'Regelstrecke' (the process) which would literally translate as control path and has a different genealogy to the words used in English. Similar examples are 'Nachstellzeit' for integral time, which translates as readjustment-time and 'Vorhaltezeit' for derivative time, which translates as lead-time.

– I have been working in process automation for over two decades, both in an English and a German speaking environment. When I went to a production site where one of my students is doing his Master's thesis, I did not understand parts of the conversation among production staff and control engineers which concerned a 'Standregelung'. It literally means standing-control in German, which made no sense to me. After enquiring, I found out that 'Standregelung' was actually 'Füllstand-Regelung' but they had shortened the word by dropping the prefix. 'Füllstand' is level. So the conversation was simply about a level control problem, not a control strategy that I had never heard of. - Margret Bauer

5. DISCUSSION

Inevitably, students from different countries, different universities, maybe taught by different teachers at the same institution, or by reading different books will get used to and use different words and terminology. It might become even more complicated if different students in the same course read different books using a diverse set of terminology – something that happens regularly for courses with international students that might also look at books in their native language or English in parallel to material in the course's language. Specially during the

Table 2. Basic control terminology, English, Swedish and German. Terms marked with [1] refer to Thomas (2016), [2] refers to Glad and Ljung (2006).

Category	English	Swedish	German
Signal, r	Reference	Börvärde[1], Referenssignal[1,2]	Führungsgröße, Sollwert
Signal, y	Process output	Ärvärde[1], Mätsignal[2] Utsignal[2]	Regelgröße, Istwert
Signal, e	Control error	Reglerfel[1,2] Regleravvikelse[1]	Regelabweichung
Signal, u	Manipulated variable	Styrsignal[1,2]	Stellgröße
Signal, d/n	Disturbance	Störning[1,2]	Störgröße
Signal, d	Load disturbance	Processtörning[1], Laststörning[1]	Laststörung
Signal, n	Measurement noise	Mätbrus[1,2]	Messrauschen
Blocks	Controller	Regulator[1,2]	Regler
Blocks	Actuator	Styrdon[1], Ställdon[1]	Stellglied
Blocks	Process	Process[1,2], Reglerobjekt[1], System[1,2]	Regelstrecke
Blocks	Sensor	Givare[1], Mätdon[1]	Messglied
PID, K	Controller gain	Regulatorns förstärkning[1,2]	Regelverstärkung
PID, T_i	Integral time	Integreringstid[1]	Nachstellzeit
PID, T_d	Derivative time	Derivatatid[1]	Vorhaltezeit

critical phase of learning the basics of control, this may create an unnecessary hurdle, and extra cause for confusion and misconception that otherwise would not exist.

The solution is, however, not to dissimulate the divers set of terminology or discourage students to read different books, but rather should be embraced and discussed openly. This will not only ensure that students may read a diverse set of literature but also allows them to reflect about the importance of non-technical aspects such as choice of words and enable them to read advanced books or scientific papers in the future. In some cases, learning about alternative names will also allow to gain a deeper understanding or a different perspective onto control aspects and hence may even lead to a learning gain beyond the mere vocabulary.

Beyond the classroom, openly discussing these issues in university courses will also educate the next generation of control engineers to be more aware of taxonomy issues and help to prevent misunderstandings such as the anecdotes reported above. The same holds, of course, for practitioners when reading this paper.

6. CONCLUSIONS

In this article, an overview of the most frequently used control terminology has been given, both for the basic control loop and PID controllers. Like all languages, the terminology is continuously evolving and it is important to be aware of different terms. Real-life examples as experienced by the authors show how easily miscommunication can occur. PID control terminology is possibly even less defined, with contradicting terms for the PID structures and undefined tuning adjectives. A wide vocabulary can be found in the English and Swedish language while German terminology is arguably more static.

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