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An Offensive Approach to Teaching Information Security: "Aachen Summer School Applied IT Security"

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Abstract. There is a general consensus that courses on data security at university degree level should be research-oriented and teach fundamentals of the field, i.e., items of long-term knowledge in contrast to technology-oriented system knowledge. Unfortunately, this consensus often results in courses that are either too theoretical or are outdated with respect to current developments in security technology. To understand the importance of information security, students should have the possibility to gain practical experience how security systems fail, using offensive techniques.

In this article, we give an overview over a three-week intensive course on applied computer security we held at RWTH Aachen university. It brought together students from various countries and with different previous knowledge. We describe in detail the course outline, course contents and the lessons learned.

1 Introduction

The ACM Curricula Recommendations [ACM] have had profound influences on academic computer science curricula in use at educational institutions throughout the world. These recommendations also mention the term *Security* as a part of academic education but unfortunately do not specify in what way this topic should be taught. Reviewing the standard courses in IT security given at major US and European universities, we observe that the courses focus on either theoretical aspects of information security (e.g. encryption) or defensive approaches like intrusion detection systems and firewalls. In our view, this leaves computer science graduates ill-prepared for their professional career because they lack both hands-on knowledge on how to deal with security technology or they always trail active adversaries in their efforts to master them.

In summer term 2004 the Laboratory for Dependable Distributed Systems at RWTH Aachen University offered a novel course in the area of information security: The Summer School "Applied IT security" gave graduate and Ph.D. students a deep understanding of issues in computer security. The distinguishing feature of this course was its "offensive" approach. Offensive can mean two things: it either refers to items which are "designed for attack" or items which "give painful or unpleasant sensations" [Lon95]. The first meaning is the primary one for this course and often implies the second: We took an approach with explicit

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intentions of attacking systems. This approach, also advocated for example by Arce and McGraw [AM04], is uncommon for an academic curriculum, in which theoretical foundations are often preferred over practical aspects. But due to the fast development in the area of information technology and especially information security, we think that it is of eminent importance to train future computer science professionals in the ways of thinking of their adversaries. Furthermore, we aim at bringing a solid foundation to research in this area and contribute some ideas to enhance the field and the associated curriculum.

During the three week period, we gave the students the possibility to learn on the one hand theoretical basics and on the other hand practical implications of security problems. We focused on offensive techniques and procedures, e.g. we gave lectures on exploitation of programming errors, wireless (in)securities, and sniffing and spoofing. In this paper, we give an overview over the course and present in detail the lectures and exercises we offered. This may inspire others and leads to a tighter integration of security in university curricula.

Some words on "hacker" courses: Our method of teaching information security is an aggressive one. We teach students how to find "interesting" systems, how to exploit systems, how to hide traces, and more. This seems to offer the students knowledge which they can abuse later for malicious purposes. But we think the opposite is true: One has to understand how an attacker proceeds in order to develop new methods for defense. To quote White and Nordstrom [WN98], who taught a similar course at the United States Air Force Academy in 1998:

> There are scores of hackers operating throughout the Internet today. We believe that hiding their techniques from our students only leads to a generation of system administrators who are "sitting ducks" for the hackers that are out there. We use a knowledge of security holes to teach our students what must be done in order to secure their own systems.

Furthermore, our selection process (based on prior experience, expected willingness to work hard, and interest in scientific work) aimed to ensure that participants were in a position of being able to judge their actions and apply their knowledge in a responsible way.

The rest of this paper is structured as follows: Section 2 describes related projects in the area of teaching information security. Section 3 describes the concept and organization of the Summer School, whereas Section 4 presents the lectures and exercises in detail. In Section 5 we analyze the lessons we learned during the Summer School. Finally, we conclude our work and experience in Section 6.

2 Related Projects

Although we are not aware of any efforts along the lines of the Summer School, several other projects pioneered some teaching concepts we used in the Summer School.

There have been some good attempts to incorporate practical elements of information security into university degree courses. The computer science department of Darmstadt University of Technology, Germany, regularly runs a so-called

Hacker Contest for several years [SMR00]. The Hacker Contest is a lab course in which students form teams that have to set up systems and then use common exploitation techniques to attack the systems of the other teams. The attendees also have to analyze attacks against their own systems and increasingly deploy stronger defense measures. The University of Magdeburg, Germany, also offers a similar lab course and has joined efforts with Darmstadt in that students from Darmstadt perform penetration tests of systems deployed in Magdeburg and vice versa.

There are some universities that offer courses in which the students learn the underlying concepts of offensive IT security and can also apply their knowledge. As an example, the Distributed Systems Group of the Technical University of Vienna offers courses on Internet security: Practical aspects of IT security like race conditions, viruses and reverse engineering are covered and exercises in which the students have to implement the attacks must be solved. In the military education, one can find similar examples of offensive lectures, for example [WN98].

Several projects have pioneered the use of offensive techniques as teaching concepts, but none of them has treated offensive techniques in a research-oriented way, as it is done in the Summer School. So called *Wargames* and *Capture the Flag* (*CTF*) contests have a long tradition among security enthusiasts. In Wargames, the organizer creates a set of challenging scenarios of increasing difficulty which have to be solved by the participants. Challenges usually are modeled somewhat after the problems an attacker faces when attempting a system penetration. Typical Wargames can be found at [Dig,Hac]. Slightly more competitive than Wargames are CTF or so called *Deathmatch* contests where teams compete against each other over the control of a network. Most famous are probably the annual *Root-Fu* contest [Ghe] and the CTF contest of the UCSB, in which several educational institutions spread across the United States battle against each other [Vig03,UCS].

The Information Technology and Operations Center (ITOC) at the U.S. Military Academy West Point has a curriculum which also teaches offensive information security techniques. ITOC also organizes a yearly *Cyber Defense Exercise* which has similarities to the Capture the Flag contests. U.S. authorities with an information security education branch like the United States Military Academy, the United States Air Force Academy, and the Naval Postgraduate School, participate in these exercises. Machines maintained by the participants are attacked by the NSA 92nd Aggressor Squadron – Land Information Warfare Activity over the course of several days and participants have to counter these attacks [DRR03,SJ98].

3 Concept and Organization

3.1 Goals

At university degree level, it is a rule of good academic practice to teach long-term methodological knowledge instead of short-term system knowledge. In the area of information security, this has resulted in university curricula which either tend towards theoretical topics (like cryptographic protocols or formal modeling of security) or towards practical topics highlighting defensive strategies (e.g., access control techniques, firewalls and VPNs). Information security, however, is a field which is rapidly changing. The new developments like the security threats in Web-based systems (e.g., cross-site scripting) or the dangers of so-called botnets are often neglected because professors tend to cherish their own specialized and theoretical research areas in their courses. This leaves university graduates with only faint ideas of the security threats they will face in their professional career. Moreover, a typical computer science graduate, even if she has specialized in information security, usually has very little practical experience with the way *real* systems react in the presence of malice. With the Summer School not only future researchers, but especially future software designers or project managers should experience how hardware and software fails and learn how to improve things. So we wanted to give them an impression how easily things can break.

We wanted to give the students the possibility to learn offensive techniques in information security, but also treat this topic in a research-oriented way. In addition, we want to create a network in the community of researchers interested in offensive information security techniques.

Another goal was to get participants of different skill levels to cooperate and thus foster knowledge transfer. We especially wanted to have more experienced researchers like Ph.D. students to team up with less experienced students. We hoped that this would help to introduce students to the scientific approach and possibly interest them in information security as a science.

3.2 Implementation

The staff organizing the Summer School consisted of two research assistants of the Laboratory and two students of whom one is a research student of the laboratory and the other a regular student at another university. While the three organizers from our university could – at least partly – do their preparation during their regular paid working hours, the forth organizer had to do all of his contributions in his spare time.

The intended audience were students and young scientists from Europe with a profound interest not only in information security but also in offensive techniques in relation to security. We also expected a high level degree of technical skills: Participants were expected to work hard during the Summer School and to use a wide array of tools and techniques during the lab sessions.

Since these traits could not be checked like simple requirements in an application form, we decided to use some kind of scare tactics to deter less determined students and give others the opportunity to show creativity. For example, we requested a list of publications in the application form. While some participants could offer a long list of scientific publications, we were more interested in the approach used by others. So some applicants put advisories or even newsgroup postings in their applications – we generally preferred that over “None”.

We did only low profile advertisement for the Summer School. Besides announcing it during the lectures given by the members of the laboratory and at our webpage, we mentioned it to friends and colleagues. In addition, we did an announcement on a mailing-list dedicated to penetration testing. Since this already resulted in more than 50 applications, we refrained from doing further advertisement.

We selected 16 students on the base of prior experience, expected willingness to work hard, and interest in scientific work. Of those 16 students selected, one was from Turkey, one from The Netherlands, four from Great Britain (three of them members of Professor Ross Anderson's security group), and 10 from Germany (Aachen, Berlin, Cologne and Gelsenkirchen). Unfortunately, two of the selected students informed us only a short time before the beginning of the Summer School that they would be unable to attend. So the final number of participants was fourteen.

The Summer School took partially place in the lecture halls of our university, which were unused during the summer break. Additionally we provided a room for the lab sessions where the students could use their own laptop computers and which held a lot of obscure hardware and complex network infrastructure to experiment with.

To foster informal communication between students, we converted an office to a coffee hall with sofas, an overall relaxed ambiance, and a choice of snacks and refreshments. Finally, there was a plain room for temporary use by students which had the feeling they need concentration for specific tasks. The housing was left to the students themselves and their choices showed a very wide variety of solutions ranging from the universities' guest-house to the local camping ground.

The schedule during the Summer School was demanding: Lectures started at a quarter to nine in the morning and covered two topics until noon. After lunch, the lab session started, during which students applied the techniques learned in the lectures and developed them further. While some of the lab sessions took a very guided approach asking students to solve specific tasks, others were more general up to the point where students were just asked to apply the knowledge gathered in the morning. For an outline of the Summer School see table 3.2.

The lab session was interrupted by a so called "coffee table talk": We invited external contributors to give a short statement related to a topic of their interest or a short introduction one some project they work on. The coffee table talks were intended to broaden the view of the participants. We aimed at showing the students problems being worked on in the real world and to teach them looking at problems not only from the security perspective. Speakers were sent by corporations ranging from Microsoft and Pixelpark up to German Postbank and the TÜV Rheinland. But we had also participants from other groups like the Chaos Computer Club (CCC) or the "Verein digitale Kultur", which covers artistic expression via digital means, and various academic research groups. Topics covered in the coffee table talk ranged from computer-ethics, civil liberties in relation to the Internet, phishing attacks from a banks perspective, up to highly technical subjects like attacks on memory management and XML security.

A typical day ended with a meeting: usually around six in the evening everybody presented his work of the day. But students often stayed through large parts of the night to develop their projects further.

4 Running the School

4.1 First week

On the first day (September 20) we started with a brief overview over the whole Summer School and gave the people the possibility to introduce themselves. We

Day	Lecture 1	Lecture 2	Lab
	8:45-10:15	10:45 - 12:15	at least until 18:30
Week 1			
1	Introduction	Hardware Security	Hardware / Wargames
2	Web Applications	Web Applications	Web Applications
3	Buffer Overflows	Other Programming Errors	Exploiting Overflows
4	Advanced Exploitation	Networking	Network Programming
5	Sniffing: Layer 1 & 2	Spoofing, DoS & DDoS	Sniffing & Spoofing
Week 2			
1	Network Topology	Application Fingerprinting	Network mapping
2	Bluetooth	Wireless Attacks	Wardriving
3	Hidden Data	Honeynets	Wardriving
4	Introspection	Projects	Projects
5	Projects	Projects	Projects
Week 3			
1	Misc. Forensics	Disk Forensics	Forensics
2	Disk Forensics	Disk Forensics	Forensics
3	Malware Unix	Unix infection	Honeynets
4	Excursion	Excursion	Excursion
5	Wargame	Wargame	Wargame

Fig. 1. Schedule of the Summer School

tried to give them an insight into our expectations for the upcoming three weeks and also wanted to know their wishes. After this introductory lecture the first "real" lecture took place: "Hardware Hacking" was the topic and the students got an insight into limitations and vulnerabilities of hardware devices. During the lab session, the students opened some devices (e.g. cable modems, router, switches) to inspect the insides. They also played some wargames like `www.hackthispage.tk` and averaged at about five levels.

The topic of the second day was "Attacks Against Web Applications": One lecture concentrated on general problems in web applications (e.g. SQL injection and cross site scripting), while the other had the special focus on programming errors on web-applications written in PHP, a scripting language that is quite popular among developers. The corresponding lab session had no very tight focus. The students should find bugs in real web applications. They did not like this exercise, probably they were missing some guidelines. During the afternoon George Danezis, one of the participants and research assistant from the university of Cambridge, gave a talk on "Anonymous Communication".

On Wednesday, the lectures concentrated on buffer overflows and other programming errors. This is a very broad topic and probably two lectures are not enough to cover the whole field. Therefore, these two lectures concentrated on the basics and two other coffee table talks deepened the knowledge of the participants. The lecture "Buffer Overflows" gave an overview of some techniques to exploit buffer overflows and the second lecture concentrated on other common programming errors. The lab session was quite popular at this day: The students should exploit various programs and they apparently had much fun doing this. For many people, this was their first exploit and they were quite proud to be able to write one. One student also found some bugs in real applications (e.g. a format-string vulnerability in Tor, an anonymizing overlay network for TCP) and further examined them. In cooperation with the authors of the software, these holes were fixed. "Phishing" was the topic of the coffee table talk and an IT-security specialist of a large German bank explained the threat.

"Advanced / Automatic Exploitation" was the topic of the first lecture on Thursday. This talk dealt with some tools that aggressors can use for attacks, e.g. the Metasploit Framework, search engines like Google to collect information, etc. In addition, the art of fuzzing, a technique to find errors in a given program in a semi-automated fashion, was presented. The second lecture repeated necessary knowledge on communication networks and gave an introduction to network programming and the important libraries (e.g. libnet, libpcap). Implementation of covert channels, ARP-spoofing and various other tools were the focuses of the lab session. The students could choose which technique they wanted to implement and it worked out well. Jens Ohlig from the Chaos Computer Club gave a historical overview about political activism and hackers during the coffee table talk.

On Friday, sniffing & spoofing and (distributed) denial-of-service (DDoS) attacks were covered. The lectures gave an overview of tools and techniques used to sniff passwords and other sensitive information on networks. The lectures also explained how to spoof packets in order to receive interesting packets and gave a background on (distributed) denial-of-service attacks. During the lab session, the student experimented with the available tools and also implemented some small programs for ARP-spoofing and similar techniques. Many attendees were surprised how easy it is to sniff passwords even in switched networks and got an insight in why encryption should be used whenever possible. The coffee-table talk entitled "XML Security" was given by Christian Geuer-Pollman from the European Microsoft Innovation Center (EMIC), Aachen.

4.2 Second week

The next week started with a lecture on network reconnaissance. This lecture covered techniques to find useful information about targets and first steps of an attacker after a successful compromise. It also introduced some common fingerprinting techniques for OSI layers 2-4. The second lecture focused on further steps after an intrusion and covered application fingerprinting in depth. During the lab session, we tested something new: We gave the not that dedicated students a mandatory exercise. They should parse the data structures of some fingerprinting tools and use these in self-written applications. The students did not like this exercise, they were forced to do something boring and somehow lost the motivation. This was the only day we had a mandatory exercise. Beside this, the students were encouraged to do portscans of the network of our university. The center for computing and communication explicitly allowed us to do this and we found some security holes during these tests: One student found several routers with default passwords and another tracked down some printers that could be managed remotely via a web-interface. In cooperation with the responsible persons from the center for computing and communication these security holes are now fixed. Penetration-testing for phone-systems was the topic of the coffee-table talk on this day. Rolf von Stein from TÜV Secure IT explained the motivation behind this and gave some background information.

Wireless Security was the focus on Tuesday: The first lecture with the title "Bluetooth Security" introduced the attendees to the basics of the Bluetooth standard and pointed out some attacks. The focus of the second lecture was on WLAN (mainly 802.11b) and also a small introduction to RFID and its concerns was given. During the afternoon, the students were able to gain experience in so called "wardriving", the challenge of finding wireless LANs. They drove through the city and found more than 100 wireless LANs in total. The collected data were handed over to researchers at our university who are involved with wireless networks for further analysis. The question "Where is information security today and what in the future?" was answered during the coffee-table talk by Dogan Kesdogan, a research member of the Chair of Computer Science 4 from RWTH Aachen University.

On Wednesday we demonstrated some of the current research topics of the Laboratory for Dependable Systems: The first lecture covered "Hidden Data In Documents" and explained that there are many interesting data in proprietary formats that can be misused. The second lecture gave an introduction to honeynets and related security research. It also covered an attack on the monitoring software commonly used on honeypots – a result of the honeynet research at our laboratory. Like the day before, interested students had the possibility to search for wireless LANs in the city. Some participants stayed at the lab and developed their projects further. One project was especially interesting: One attendee wrote a crawler which automatically searches for images with an included thumbnail in the Exif header. At the end of the Summer School, he had downloaded about 3.000.000 images, from which about one percent had a significant difference between the image and the included thumbnail. This showed that a significant amount of images has interesting data hidden inside the document itself. At this day, one of the students prepared the coffee-table talks: Ilja van Sprundel filled with his talk on heap-based overflows a gap that was left by the lectures on programming errors.

The rest of the week gave the students the possibility to do some research on their own and implement novel techniques. To prepare this, we collected ideas for further research on Thursday morning. From Thursday noon until Friday evening, the participants had time to implement their projects. The resulting projects covered tools for covert channels and fingerprinting applications. Furthermore, a fuzzing framework and low level network libraries were implemented and an embedded device was introspected. The coffee-table talk on Friday gave an insight into the relation between project management and security. Rainer Lingmann from Pixelpark gave a talk entitled "IT-Security: Das Gretchenprojekt aus Projektmanagment Sicht".

4.3 Third week

The last week started with two lectures about computer forensics. These lectures covered the basic of disc forensics and gave an introduction on computer forensics in general. During the lab session the students had to solve a game: We gave them a Compact Flash card which we pretended to have retrieved from a suspected terrorist. They had the task to reconstruct the corrupted files and retrieve as much information as possible, especially the place and time for the next "terrorist meeting". The attendees had much fun with this challenging exercise and many were able to recover the damaged files. The second task for this afternoon was forensic imaging of used hard discs that we had previously bought at ebay. With this exercise we wanted to verify some results which were published by Garfinkel and Shelat in [GS03]. The students found some hard discs which contained information that is both confidential and recoverable: One disc was obviously the former hard disc of a cashier terminal or cashier computer because we found bills and accounting information on it. Another hard disc was used in a bookstore before and contained many hundreds of e-mails with partially sensitive information. And a third hard disc was obviously used in a mailbox and the students were able to reconstruct the user database. How to realize "Software Detection of Currency" was presented by Steven Murdoch, a participant of the Summer School and Ph.D. student from Cambridge. He presented ongoing research he is currently doing in the security group at his university [Mur04].

An external guest gave two lectures on Tuesday: Knut Eckstein from the NATO C3 Agency talked about "Advanced Filesystem Forensics – Journaling Filesystems". More forensics of disk images was the topic of the lab session. This was too much forensics, and the students got bored. During the coffee table talk, a member from the Chaos Computer Club Cologne presented *grsecurity*, a suite of patches for the Linux kernel that are an attempt to improve the security of a Linux system.

The lectures on Wednesday concentrated on malware for Linux. The first talk gave a general introduction to the topic and presented rootkits and backdoors. In contrast to that, the second lecture concentrated on code infection for ELF binaries. During the lab session, the students deepend the knowledge gained during the lectures and some wrote ELF modification code. One of the students provided a small challenge for the lab session: Lisa Thalheim prepared an ELF binary and posed some questions. These tasks were demanding for the students, but most of them were able to solve them. Interestingly, at least three different approaches were used and this again showed the creative nature of the participants. In addition, the coffee table talk was prepared by Ilja van Sprundel. He talked about format-string attacks and filled another gap that was not covered during the lectures on exploitation of programming errors.

An excursion to some abandoned industrial sites was arranged for Thursday. We wanted to have an alternation to the usual schedule and therefore organized a trip to a coking plant in Essen, a gasholder in Oberhausen and some geocaching locations in Wuppertal. The main goal for this tour was fun and getting to know each other better.

We used the last day of the Summer School to get feedback on the three weeks, we will present these results in the next section. The highlight of this day was the Wargame with several levels and increasing difficulty, which Christian N. Klein had prepared beforehand. It offered the students the possibility to apply all techniques they had learned in the previous days. Fun prevailed during this game, with some minor exceptions due to missing tools. We noticed that it is very hard to get the difficulty of the levels right, we had to tweak some levels while the game was running.

4.4 After the Summer School

After the three weeks, some further noteworthy things happened. The participants of the Summer School had submitted six talks to the Chaos Communication Congress, an annual meeting of hackers organized by the Chaos Computer Club.

All six submission were accepted for presentation. The participants of the Summer School also agreed to meet at the Congress again. Furthermore, the students created an "alumni" mailinglist to stay in contact with each other and exchange further ideas. They use the mailinglist on a regular basis now.

During the lab session we found several vulnerabilities and flaws. All of these weak points were reported to the authors of the software or the operators of the systems. In cooperation with these persons, the holes were fixed.

5 Lessons Learned

It turned out during the course of the Summer School that people had extremely different skill levels, but this is difficult to asses ex ante. Nonetheless cooperation between the differently skilled people worked well. Everybody explained concepts they knew about to each other and exchanged new ideas. So one of the goals – to foster knowledge transfer – was achieved. We hope that this introduced some students to the scientific approach of information security.

While the lab sessions with less guidance lead to some very impressive results, especially the less experienced students felt that they had a better learning experience in the lab sessions with more instructions. On the other hand, when during one lab session we had given a concrete and mandatory task, people felt bored and didn't like doing it. So we refrained from repeating that.

The biggest lesson we learned: Practical aspects of security and exploitation of real systems are fun for students. When the students exploited their first buffer overflow, they were very enthusiastic and worked hard to learn more. Especially the Ph.D.-students liked the knowledge about insecurities.

At the end of the Summer School participants were asked to fill out a questionnaire to give use some pointers for improvements. In summary, the feedback was mostly positive. The main criticisms were:

- Three weeks are too long, especially if the students have to work so hard and spend so much time at the courses as they did.
- Some lectures need improvements, on one hand the depth of the talks and on the other hand the understandability.

Even so they rated the Summer School as as good a concept, that they asked for a sequel.

All in all the event was a huge success but also an immense drainage on everybody's power. With more personal resources we would have had more opportunities to better prepare. Especially some of the lab sessions would have profited from a better preparation.

6 Conclusions

The Summer School was a successful experiment in approaching offensive techniques in information security from an academic angle. All three primary goals where archived: We managed to give hands-on experience in offensive techniques to participant who until then had only theoretical knowledge of threats and risks. We fostered academic research on offensive techniques – several papers are being written by participants as a result of the Summer School and the collaborative research from the Summer School led already to five successful conference submissions in October. Finally, the Summer School succeeded in promoting networking in the community of researchers interested in offensive information security techniques.

Also our secondary goal of getting undergraduate students to work close together with more experienced researchers to induct a knowledge transfer in scientific methodology worked to a certain extent. Although teams formed mostly among participants with the same level of experience, the more experienced teams acted as a role model for the others. But since we had extreme diversity in our participants – from the research assistant with Ph.D. in Cambridge to second semester students from our university and from very experienced penetration-testers to researchers which had attacked security up to then mainly from a theoretical point of view – there was still a great amount of informal knowledge transfer happening at the Summer School.

The concept of lectures in the morning followed by immediate application of the techniques learned and the challenge to further develop these techniques in the lab sessions in the afternoon was a success although it was universally acknowledged by participants and staff that there needs to be more time available in the lab sessions.

The concept of the coffee-table talks worked as we hoped: most of the talks where an inspiration for attendees and often laid the basis for prolonged discussion among participants. Also, most of the invited speakers enjoyed their visit and meeting the participants of the Summer School a lot.

But also we had to learn that three weeks of Summer School with a tight schedule put a considerable strain on both the staff and the students. In the third week we had to slow down the pace considerable. It also turned out that fulfilling other duties in the last preparation phase and during the Summer School itself puts high pressure on staff. Future events like the Summer School should be limited to two weeks and it should be ensured that the staff can dedicate its full time to the effort.

In conclusion, the concept of the Summer School was very sound and it's already planned to repeat that event in 2005.

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