Forensic Reverse Engineering with Rekall

Workshop notes

Introduction

What do we mean by "Forensic Reverse Engineering?" Not rigorous reverse engineering by reading disassembled code to decipher the inner workings of an application, but analysis techniques that allow us to observe the internal state of an application and figure out just enough of how it works. The goal here is to extract relevant information from memory with potential evidentiary value. Since that mostly relies on context, this tends to work well with software which is not deliberately trying to avoid reverse engineering. Hence the techniques discussed might be less appropriate for analysis of malware .

Like a good movie plot, this workshop's scenario is a bit contrived. We do not aim to be realistic on all fronts - especially the legal and practical aspects are a bit contrived. Please suspend your disbelief temporarily at our rather poor imagination and crime-novel like plot development. The main focus of the workshop is to provide you insight into techniques that can be applied on real cases.

This workshop is based around the paper *Forensic Analysis of Windows User space Applications through Heap allocations. M. Cohen. Proceedings of the Third International Workshop on Security and Forensics in Communication Systems, SFCS 2015.*

The solutions can be found here.

Why Rekall?

Rekall is more than just a memory analysis tool - it is a complete framework for memory analysis, and also includes a powerful interactive interface. In previous workshops we covered many of the existing plugins that Rekall already comes with. While this is useful when you encounter common situations already covered by these plugins, however most investigations have a unique aspect to it not covered by existing plugins.

This type of analysis is much easier to perform within an interactive interface. So in this workshop we focus on Rekall's interactive interface and the additional powerful analysis techniques it provides. We will not be covering the normal set of plugins that are covered in other workshops, rather we want participants to learn how to help themselves in situations that they might encounter. Especially in those cases where an existing plugin is not written already. Rekall allows an investigator to drill down into memory, and with a few basic skills, enables anyone to write their own plugin in order to address their specific needs.

Scenario - Part 1

You are a DEA agent **Hank Schrader** and you have just received a call from customs officials about an intercepted package containing some of the bluest, purest meth samples they had ever seen. The package was sent via a courier to the offices of **Madrigal Electromotive GmbH** - A large company based in Germany. Their local offices employ about 500 employees. The package is addressed to a **Mr. Homer Simpson**, a machine operator with a sad doughnut addiction.

"*This might be the breakthrough I am looking for!*" you think in delight... Finally a chance to break this large operation.

It is 10am on a Monday. You organise a controlled delivery operation and prepare to arrest Mr. Simpson when he opens the package. At 10:15 Mr. Simpson picks up the package with a puzzled look, takes it to his desk and immediately falls asleep at the keyboard.

For the next two hours a large number of people walk past Homer's desk, some borrow things from his desk. One anonymous guy can be seen stealing a doughnut from Homer's **Krispy Kreme** box - right under his sleeping nose.

Finally at noon, Homer Simpson wakes up and opens the package. To his surprise, and the surprise of the armed DEA agents, who by this stage stormed the room and arrested Homer - the package is completely empty! Mr. Simpson claims to have no idea what the package was, never ordered it and is just crying out for someone called Marge - perhaps his lawyer.

Unfortunately we have no case against Homer - he just does not look like the dreaded **Heisenberg**... That guy can't hurt a fly.

Someone must have intercepted the package while Homer was asleep. But who? Was it one of the people rummaging through Homer's desk while he was sleeping? Was it someone in the mail room?

You scramble your favourite judge and get together a search warrant. The warrant allows you to search all computer systems in the local offices of Madrigal Electromotive GmbH under the following restrictions:

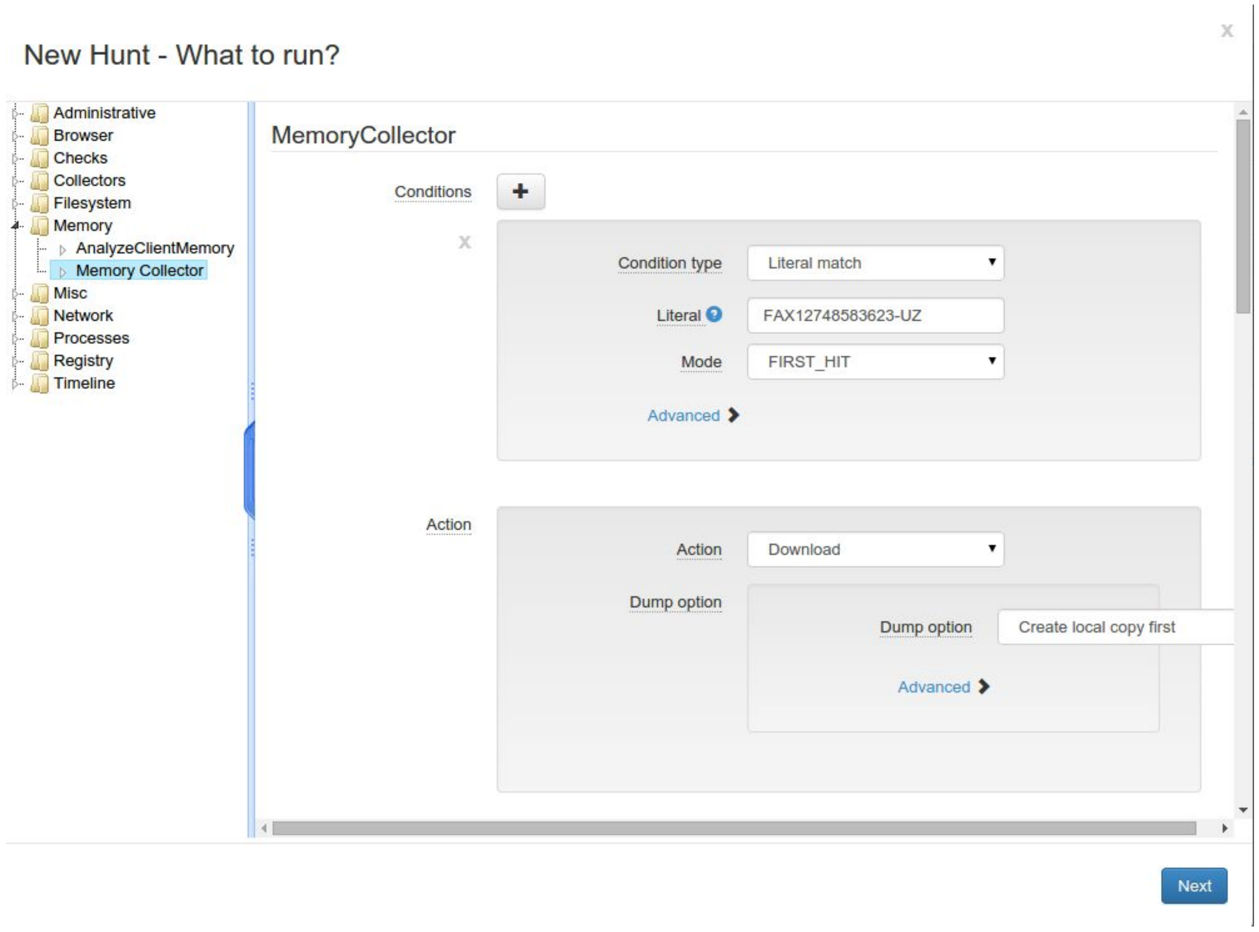
1. You may only search for information relevant to the package:
    a. The Tracking number is FAX12748583623-UZ
    b. The package is addressed to a "Homer Simpson"
    c. The package was sent from "Herr Hertzog"
2. You may not acquire any forensic evidence without probable cause!

Time is of the essence!

You speak with the IT manager and he indicates that all corporate systems are running GRR.

1. You use GRR to search memory for the keywords covered under the warrant.
2. Do you have probable cause for acquisition? Use GRR to acquire the system's memory.

Schedule a GRR Memory Collector hunt. Select a literal match for the package tracking number. Ensure that GRR makes a local copy first, and downloads the memory image.



MemoryCollector

Conditions

Condition type: Literal match

Literal: FAX12748583623-UZ

Mode: FIRST_HIT

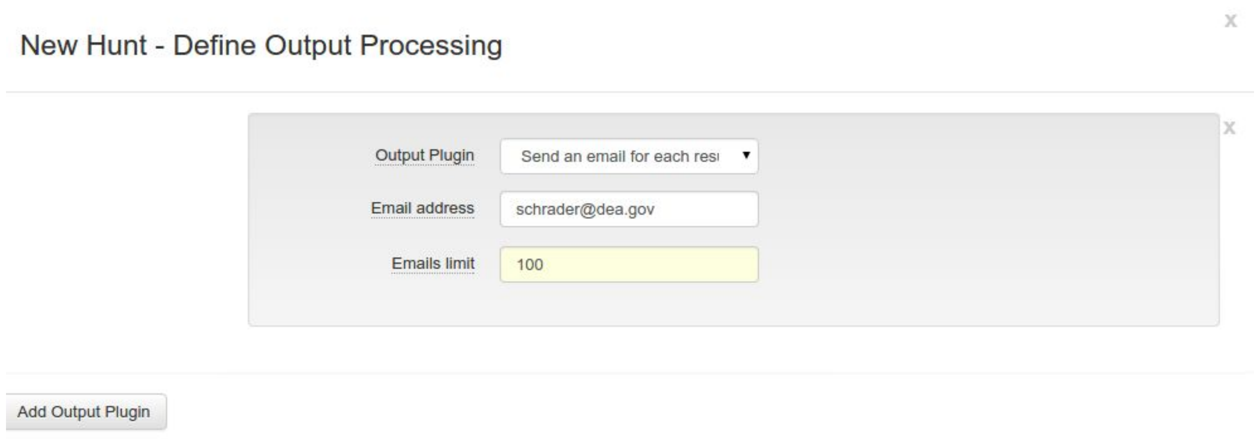
Action

Action: Download

Dump option

Dump option: Create local copy first

Have GRR send an email for each hit:

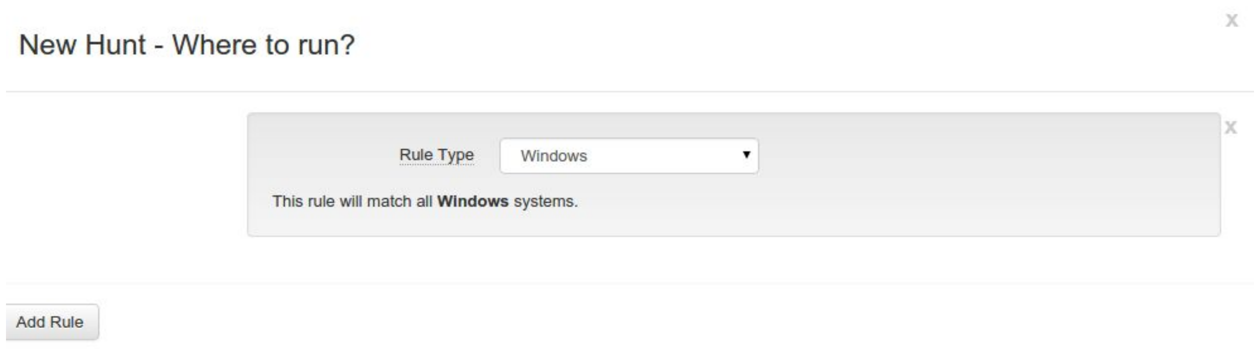

New Hunt - Define Output Processing

Output Plugin: Send an email for each resu

Email address: schrader@dea.gov

Emails limit: 100

Schedule the hunt on all the windows systems:


New Hunt - Where to run?

Rule Type: Windows

This rule will match all **Windows** systems.

Jesse Pinkman's machine returns a positive hit. There is probable cause now to acquire his machine's memory, however, we can not really tie Jesse to the package. There is not enough context to charge Jesse.

A suspicious user called **Jesse Pinkman** has the tracking number found in physical memory. You detain Jesse for questioning but his lawyer, **Saul Goodman** is challenging! Do you have enough to finally lock him up?

Exercise 1:

Copy Rekall to your workstation and begin inspecting the acquired image. In this workshop we will use the stand-alone version of Rekall - this does not require an installation. The image is called **hank.aff4.**

Search the physical memory for the tracking number.

What potential defences can **Saul Goodman** come up with to explain why the tracking number is in physical memory?

Can you refute these explanations? Consider possible counter arguments and test these theories.

Exercise 2:

You managed to pinpoint the tracking number to the process memory of the **Miranda Instant Messaging** application. This is an application used to chat with other users and a working theory is that the tracking number was delivered to Jesse over chat from the real perpetrator - maybe even **Heisenberg** himself!

Do we have enough to charge Jesse now?

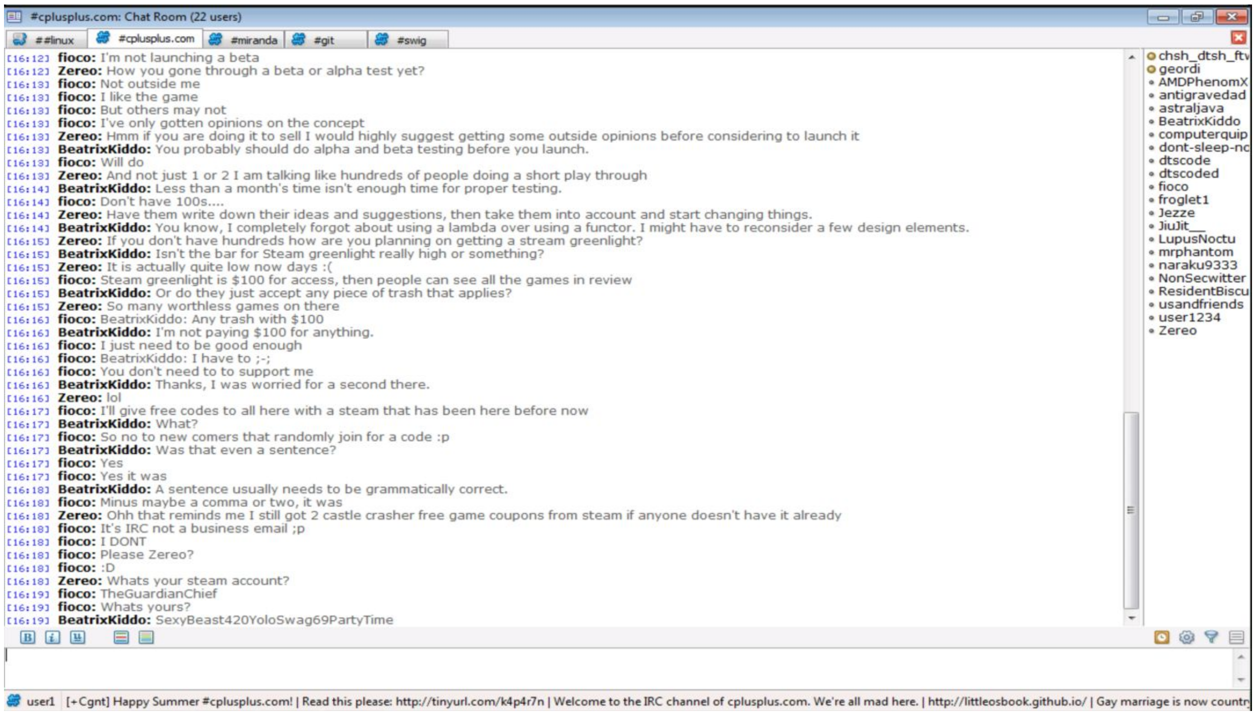
Exercise 3:

Before we can charge anyone we need to prove knowledge and intent. In particular we need to show that Jesse received, and responded to the message. We also need to know the exact time the message appeared and proof that Jesse himself responded.

In order to do this we need to work out how **Miranda IM** stores messages in memory. We have installed **Miranda IM** on our test machine and joined some IRC channels. The image is called **MirandaTest.aff4**. For the next few exercises we will use that image.

As investigators we have never even heard of Miranda IM which is not terribly popular. We search the net for Rekall plugins that can analyze it but came up empty. Looks like we have to write our own plugin.

The miranda screenshot is shown below:



```
[16:12] fioco: I'm not launching a beta
[16:12] Zereo: How you gone through a beta or alpha test yet?
[16:13] fioco: Not outside me
[16:13] fioco: I like the game
[16:13] fioco: But others may not
[16:13] fioco: I've only gotten opinions on the concept
[16:13] Zereo: Hmm if you are doing it to sell I would highly suggest getting some outside opinions before considering to launch it
[16:13] BeatrixKiddo: You probably should do alpha and beta testing before you launch.
[16:13] fioco: Will do
[16:13] Zereo: And not just 1 or 2 I am talking like hundreds of people doing a short play through
[16:14] BeatrixKiddo: Less than a month's time isn't enough time for proper testing.
[16:14] fioco: Don't have 100s....
[16:14] Zereo: Have them write down their ideas and suggestions, then take them into account and start changing things.
[16:14] BeatrixKiddo: You know, I completely forgot about using a lambda over using a functor. I might have to reconsider a few design elements.
[16:15] Zereo: If you don't have hundreds how are you planning on getting a stream greenlight?
[16:15] BeatrixKiddo: Isn't the bar for Steam greenlight really high or something?
[16:15] Zereo: It is actually quite low now days :(
[16:15] fioco: Steam greenlight is $100 for access, then people can see all the games in review
[16:15] BeatrixKiddo: Or do they just accept any piece of trash that applies?
[16:15] Zereo: So many worthless games on there
[16:16] fioco: BeatrixKiddo: Any trash with $100
[16:16] BeatrixKiddo: I'm not paying $100 for anything.
[16:16] fioco: I just need to be good enough
[16:16] fioco: BeatrixKiddo: I have to ;-;
[16:16] fioco: You don't need to to support me
[16:16] BeatrixKiddo: Thanks, I was worried for a second there.
[16:16] Zereo: lol
[16:17] fioco: I'll give free codes to all here with a steam that has been here before now
[16:17] BeatrixKiddo: What?
[16:17] fioco: So no to new comers that randomly join for a code :p
[16:17] BeatrixKiddo: Was that even a sentence?
[16:17] fioco: Yes
[16:17] fioco: Yes it was
[16:18] BeatrixKiddo: A sentence usually needs to be grammatically correct.
[16:18] fioco: Minus maybe a comma or two, it was
[16:18] Zereo: Ohh that reminds me I still got 2 castle crasher free game coupons from steam if anyone doesn't have it already
[16:18] fioco: It's IRC not a business email ;p
[16:18] fioco: I DONT
[16:18] fioco: Please Zereo?
[16:18] fioco: :D
[16:18] Zereo: Whats your steam account?
[16:19] fioco: TheGuardianChief
[16:19] fioco: Whats yours?
[16:19] BeatrixKiddo: SexyBeast420YoloSwag69PartyTime
```

```
chsh_dtsh_ftv
geordi
AMDPhenomX
antigravedad
astraljava
BeatrixKiddo
computerquip
dont-sleep-nc
dtscode
dtscoded
fioco
froglet1
Jezze
JiuJit__
LupusNoctu
mrphantom
naraku9333
NonSecwitter
ResidentBiscu
usandfriends
user1234
Zereo
```

```
user1 [+Cgnt] Happy Summer #cplusplus.com! | Read this please: http://tinyurl.com/k4p4r7n | Welcome to the IRC channel of cplusplus.com. We're all mad here. | http://littleosbook.github.io/ | Gay marriage is now countr
```

We see a number of important aspects:

1. The timestamp a message was sent.
2. Who the message was sent from.
3. The message text itself.
4. The list of users in the channel.
5. The channels currently subscribed to.

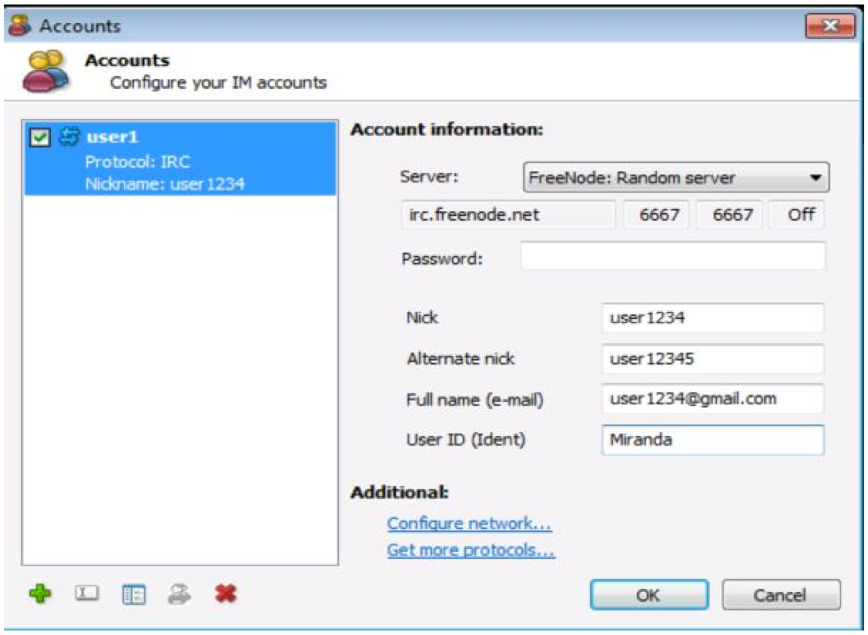
Our goal is to understand enough of how **Miranda IM** works so as to write a Rekall plugin to reconstruct the above data from the memory image. Using this information we can find the context around the keyword hit and thereby ensure that the suspect had **Mens Rea**.

- Switch to the miranda process context and enumerate all heap allocations.
- Find the strings in the screenshot above within the Miranda process. The following plugins are useful (you can read their documentation on the Rekall documentation site):
    - grep
    - yarascan
    - sigscan
- Inspect the heap allocations (using the **inspect_allocation** plugin) that contain these strings. Note that the string would appear multiple times as part of a number of different subsystems (can you tell them apart?):
    - Miranda IM internal data structures

    - GUI structures maintaining the visual elements themselves (part of the windows UI toolkit).
- Inspect references to these allocations using the **show_referrer_alloc** plugin. Try to determine a pattern between the messages, and the data structures which refer to them. It is useful to draw a picture to visualize relationships between structures. Common data structures include (try to recognize these by sight):
    - Doubly linked lists
    - Singly linked lists
    - Counted strings (i.e. length followed by string).
- Write Rekall Struct definitions to define a specific profile for the Miranda IM program. Use the profile interactively to inspect allocations.
    - Below is an example skeleton file to get you started (you can run it from the console using "*run -i test.py*":

```
from rekall import obj
from rekall.plugins.overlays import basic

# These are the private type definitions... Add fields to this as you figure out
# more about Miranda's private types.
TYPES = {
  "MESSAGE_RECORD": [0x50, {
         "Message": [0, ["Pointer", dict(
              target="UnicodeString"
         )]],
}

# This is needed so you can reload this file over and over. We remove previous
instances
# of the Miranda profile from the registry.
obj.Profile.classes.pop("MirandaProfile", None)

class MirandaProfile(basic.ProfileLLP64, basic.BasicClasses):
    """A basic profile for Miranda IM."""

    @classmethod
    def Initialize(cls, profile):
        super(MirandaProfile, cls).Initialize(profile)
        profile.add_types(TYPES)

miranda = MirandaProfile(session=session)
```

These are some screenshots of the Miranda user interface. In this case we only care about IRC messages but for extra credit... our plugin could extract all configured information (e.g. user nicks, passwords for private channels etc). Try to explore how Miranda keeps its own configuration information so our plugin can extract this from memory.



Accounts

Accounts
Configure your IM accounts

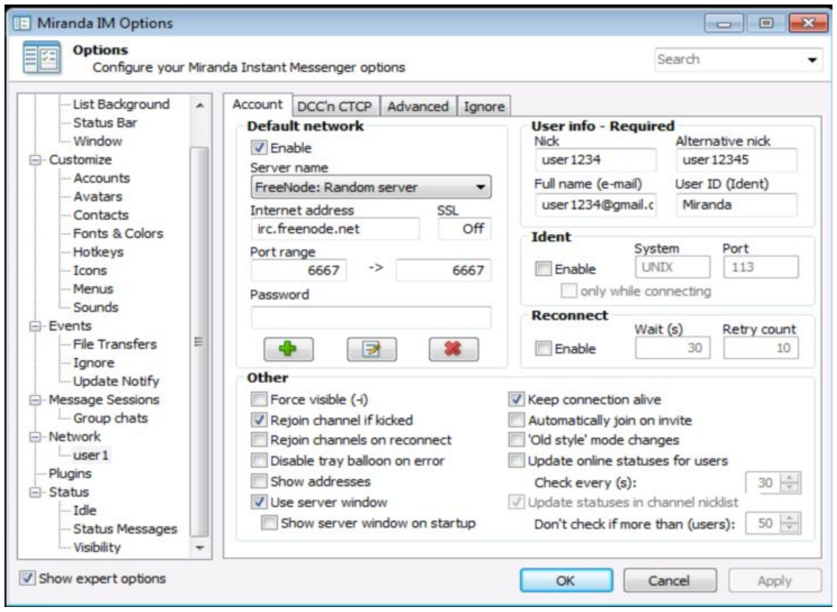
user1
Protocol: IRC
Nickname: user1234

Account information:

Server:	FreeNode: Random server
	irc.freenode.net 6667 6667 Off
Password:	
Nick	user1234
Alternate nick	user12345
Full name (e-mail)	user1234@gmail.com
User ID (Ident)	Miranda

Additional:
Configure network...
Get more protocols...

OK Cancel



Miranda IM Options

Options
Configure your Miranda Instant Messenger options

Account | DCC'n CTCP | Advanced | Ignore

Default network
✓ Enable
Server name: FreeNode: Random server
Internet address: irc.freenode.net SSL: Off
Port range: 6667 -> 6667
Password:

User info - Required
Nick: user1234 Alternative nick: user12345
Full name (e-mail): user1234@gmail.c User ID (Ident): Miranda

Ident
☐ Enable System: UNIX Port: 113
☐ only while connecting

Reconnect
☐ Enable Wait (s): 30 Retry count: 10

Other
☐ Force visible (-i)
✓ Rejoin channel if kicked
☐ Rejoin channels on reconnect
☐ Disable tray balloon on error
☐ Show addresses
✓ Use server window
☐ Show server window on startup
✓ Keep connection alive
☐ Automatically join on invite
☐ 'Old style' mode changes
☐ Update online statuses for users
Check every (s): 30
✓ Update statuses in channel nicklist
Don't check if more than (users): 50

✓ Show expert options

OK Cancel Apply

Exercise 4: Write a reusable plugin

We can write a reusable plugin using our test image.

You can load an external plugin using the --plugin command line flag:

```
$ rekal -v -f MirandaTest.aff4 --plugin miranda.py
```

The skeleton of a plugin is:

```
from rekall import scan

from rekall.plugins.overlays import basic
from rekall.plugins.windows import common

TYPES = {
    "MESSAGE_RECORD": [0x50, {
        "Message": [0, ["Pointer", dict(
            target="UnicodeString"
            )]],
.....
        }],

    "CHANNEL_RECORD": [0x50, {
.....
        }],

    "CHAT_RECORD": [96, {
....
        }],

    "USER_RECORD": [0x28, {
...
        }],

    "CHATS": [48, {
...
        }]
    }

class MirandaProfile(basic.ProfileLLP64, basic.BasicClasses):
    """A basic profile for Miranda IM."""

    @classmethod
    def Initialize(cls, profile):
        super(MirandaProfile, cls).Initialize(profile)
        profile.add_overlay(TYPES)


class Miranda(common.WindowsCommandPlugin):
    name = "miranda"

    def FindChannels(self):
        """Finds channel records."""
        ......
    def render(self, renderer):
        # Create a specialized miranda profile with our reversed structs.
        self.miranda_profile = MirandaProfile(session=self.session)

        # We need to switch into the Miranda process address space!
        with self.session.plugins.cc(proc_regex="miranda") as cc:
            cc.SwitchContext()

            # Find all the channel records.
            for channel in self.FindChannels():
                # For each channel we start a new section.
                renderer.section("Channel {0} {1:#x}".format(
                    channel.Channel, channel))

                # Gather all the users
                users = []
                for x in channel.FirstUser.walk_list("NextUser", True):
                    users.append(unicode(x.Nick.deref()))

                # Make a new table for users so it gets wrapped.
                renderer.table_header([("Users", "users", "120")])
                renderer.table_row(",".join(users))

                # Make a table for messages.
                renderer.table_header([
                    ("Timestamp", "timestamp", "30"),
                    ("User", "user", "20"),
                    ("Message", "message", "80"),
                ])

                for record in channel.FirstMessage.walk_list(
                        "Next"):
                    renderer.table_row(..., ..., ...)
```

Once a plugin is written, try to run it on the actual evidence file **hank.aff4**. Is your plugin robust enough to be used in multiple images? How did Homer find out about the package? Is Jessie innocent?

Hint 1: Scanning:
You can scan a process address space for a string (or many strings) using the scan.MultiStringScanner(). This is how to use this:

```
from rekall import scan

scanner = scan.MultiStringScanner(
    session=session, needles=["signature1", "signature2"])
```

```
maxlen = session.GetParameter("highest_usermode_address")
for hit_offset, string_hit in scanner.scan(maxlen=maxlen):
     .........
```

Hint 2: Scanning for references:

To efficiently scan for pointers to a set of addresses, we can use the PointerScanner:

```
from rekall import scan

scanner = scan.PointerScanner(
     session=session, profile=session.profile,
     pointers=[x+4 for x in irc_hits])

for referrer in scanner.scan(maxlen=maxlen):
    .........
```