

Data Mining 2

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RESOURCE OUTLINE LABEL

- Regular expression concepts

Outline

1. Motivation	2
2. Regular Expression Concepts	12
2.1. Metacharacters	14
2.2. Characters Sets	17
2.3. Repetition Expressions	22
2.4. Grouping and Alternation Expressions	27
2.5. Anchored Expressions	29
2.6. Capturing Groups and Back References	30
3. Examples	31
4. Python Implementation of Regular Expressions	35
5. Final Thoughts	38

Example 1 — DNA, Repressed Binding Sites

- DNA can be represented as a loooooong string sequence consisting only of characters "A", "C", "G", and "T".
- Want to find particular sub-sequences, but these sub-sequences can have multiple variations.
- A **repressed binding site** has the following sub-sequence variations*





⇒ Some possible[†] sub-sequences denoting a **repressed binding site** are

"AGGCATGTCCTAACATGCCT"

"AGGCATGTTTAAACATGCCT"

"GGACATGTCCTAACATGCCC"

"GGACATGTCCTAACTTGTGC"

*I'm treating the patterns  and  as identical, and both mean that either "A" or "G" can appear with equal probability, etc. (reality is more complicated, but if Trump can ignore it, then so can I)

[†]Not to bring back horrible memories of *Discrete Mathematics*, but how many variations are possible?

Example 1 — Naive (=non-RE) Implementation



- Naive-naive python implementation — using only syntax common in other languages.

example_binding_sites.py

```
57 for i in range(0, len(dna) - 19):
```

```
58     if ((dna[i] == "A" or dna[i] == "G") and
59         (dna[i+1] == "A" or dna[i+1] == "G") and
60         (dna[i+2] == "A" or dna[i+2] == "G") and
61         (dna[i+3] == "C") and
62         (dna[i+4] == "A") and
```

... and skip a few lines ...

```
76         (dna[i+17] == "C" or dna[i+17] == "T") and
77         (dna[i+18] == "C" or dna[i+18] == "G") and
78         (dna[i+19] == "C" or dna[i+19] == "T")):
79             print ("Sample_%d_(%s):_match_found_at_pos_%s" % (k, dna, i))
80             break
```

```
81 else:
```

```
82     print ("Sample_%d_(%s):_no_match_" % (k, dna))
```

Example 1 — Regular Expression Implementation



- Similar regular expression implementations in c/c++, java, javascript, haskell, perl

First, load regular expression module and create regular expression pattern to compare against ...

example_binding_sites.py

```
import re
r = re.compile(r"[AG]{3}CATG[TC]{4}[AG]{2}C[AT]TG[CT][CG][TC]")
```

Then, search for matching sub-sequences ...

example_binding_sites.py

```
m = r.search(dna)
if m != None:
    print ("Sample_%d_(%s):_match_found_at_pos_%s" % (k, dna, m.start()))
else:
    print ("Sample_%d_(%s):_no_match_" % (k, dna))
```

Implementation needed two lines, line 34 to define the regular expression, and line 39 to test for a match.

Example 2— Date/time Identification/Parsing

Consider the problem of standardising date and time information from unstructured data source (i.e., free form text input).

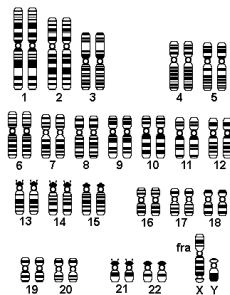
For example, your last practical assignment will be to analyse a set of (≈ 1000) medical notes — each one-line entry contains a (partial) date but the formatting was not consistent, and includes variation such as:

- month/day/year (with(out) leading zero, two or four digit year),
e.g. "04/20/2009". "04/20/09"; "4/3/09"
- Mixture of delimiter symbols ("/", "\" or "-")
- Month (partially) written out (and order changing)
"Mar-20-2009"; "Mar 20, 2009"; "20 March, 2009"; etc
- Use of ordinal numbers
"Mar 20th, 2009"; "Mar 21st, 2009"; etc
- Partial dates
"Feb 2009"; "6/2008"; "2010"

This can be accomplished without regular expressions but is a pain.

Example 3 — DNA, Fragile X Syndrome

- **Fragile X syndrome** is a genetic condition that causes a range of developmental problems including learning disabilities and cognitive impairment. Usually, affecting males more severely than females.
- Within the **FMR1** gene is a sub-string containing triplet repeats of "CGG" or "AGG", bracketed by "GCG" at the beginning and "CTG" at the end.
- Number of repeats is variable and is correlated to syndrome.



Regular Expression

expression

GCG(CGG|AGG)*CTG

string

...GCGGCGTGTGTGCGAGAGAGTGGGTTTAAAGCTG**GCGC** **GGAG-**
GCGGCTGGCGCGGAGGCTG ...

Summary (Before we start!)

“Some people, when confronted with a problem, think ‘I know I’ll use regular expressions.’ Now they have two problems.”

— Jamie Zawinski (flame war on alt.religion.emacs)

- ✓ Regular expressions can match arbitrary complex sub-strings.
- ✓ Simpler, shorter and less error-prone than using standard control statements.
- ✗ Can get very complicated and difficult to debug.

Regular expressions is vital skill for any programmer, sys admin, data analyst, etc..

Just use regular expressions up to the level of complexity that you feel comfortable with.

- Regular expressions are **greedy** (match as many characters as possible) and **eager** (stops as soon as a match is found).

[illegible]

Regular Expressions as a Classification Problem

When building regular expression you need to be mindful of two antagonistic aims:

- make expression permissive enough to match desired patterns
 - make expression restrictive enough to exclude undesired patterns
-

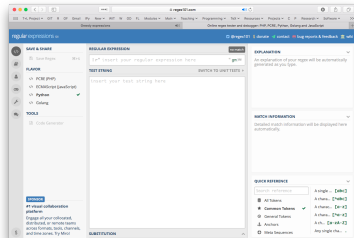
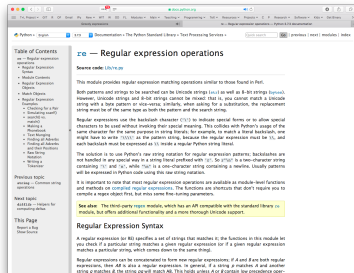
Or if you think in terms of errors — we have two kinds of errors

- Matching strings that we should not have matched
False positives (Type I)
- Not matching things that we should have matched
False negatives (Type II)

Hence can think of constructing a regular expression as a classification task — and reducing the error rate for an regular expression involves two efforts:

- Increasing **precision**, (minimising false positives)
- Increasing **coverage**, or recall, (minimising false negatives)

Resources



<https://regex101.com>

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Literal Characters

- Letters and digits match themselves
- Normally case sensitive
- Watch out for punctuation characters — most of them have special meanings!

Example

Given text

“A_Jack_and_Phil_went_up_a_hill. ”

then regular expressions

- `/hil/` matches

A_Jack_and_Phil_went_up_a_hill.

- `/a/` matches

A_Jack_and_Phil_went_up_a_hill.

- `/il./` matches

A_Jack_and_Phil_went_up_a_hill.

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Literal Characters

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- `/il./` matches

A_Jack_and_Phil_went_up_a_hill.

Metacharacters

\ . * + - { } [] ^ \$ | ? () : ! =

- Characters with special meaning

- escape — transform literal character to/from metacharacter

\

- wildcard operator (represents any character)

.

- set of characters

[]

- ranges of characters

-

- repeats — zero or more/one or more/range

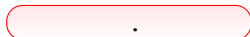
* + { }

- start/end of string

^ \$

- Can have more than one meaning — depends on context.

Wildcard Metacharacter



- The wildcard represents any single character except the newline.
 - Original unix regex engines were line based tools.

- `/h.t/` matches

The h o t M A G A h a t s a t o n t h e a t e d h o b .

- Widest match character.

- Common mistake when matching numbers `/9.00/` matches

9.00 v s 9 500 v s 9:00

Escape Metacharacter

A red rounded rectangle containing a backslash character (\).

- Allows use of metacharacters as literal characters
- Match as period with `/\./`, for example `/9\.\00/` matches
9.00_vs_9500_vs_9:00
- Match backslash using `/\\`
- Convert literal characters to metacharacter (if defined).
- Note quotation characters are not metacharacters.

Characters Set

[]

- The string of characters inside the braces specifies a disjunction (ORing) of characters to match.
- Order of characters does not matter — is a set

Examples

- `/[aeiou]/` matches any one vowel, i.e.,

My_queue_is_not_a_stack
↑↑↑↑↑↑↑↑↑↑

- `/gr[ae]y/` matches

Is_the_colour_gray_or_grey?
↑↑↑↑↑

- `/[01234567890]/` matches any one vowel, i.e.,

8_out_of_10_cats_does_countdown
↑↑↑↑↑

Warning

In first and third example we only did repeated matching of SINGLE characters.
For example, we did not match “8” and “10”, but matched “8”, “1”, and “0”.

Characters Range



- Range metacharacter
 - Represent all characters between two characters (inclusive).
 - Only a metacharacter inside a character set, a literal dash otherwise.

Examples

- `/[0-9]/` matches any integer.
- `/[A-Za-z]/` matches any letter.
- `/[a-ek-ou-y]/` matches any letter from 'a' to 'e', from 'k' to 'o', and from 'u' to 'y' inclusive.
- Warning: `/[50-99]/` does not match all numbers from 50 to 99. It is the same as `/[0-9]/` or `/[0-99999]/` or ...

Negative Characters Sets

^

- Negative metacharacter.
 - Indicates not any one of several characters.
 - Must be first character inside a character set — otherwise is treated as a literal character.
 - Resulting character set still represents a single character.

Examples

- `/[^aeiou]/` matches any non-vowel, i.e.,

My_queue_is_not_a_stack

(Note: I'm also matching the spaces.)

- `/[^aeiou]/` matches space, any vowel, or the character “^”, i.e.,

My_queue_is_not_a_stack

- `/[Ss]ee[^mn]/` matches

The_Seeker_does_see_but_does_not_seem_to_have_seen.

(Note: Matched “see_” because of the trailing space.)

Metacharacters inside Character Sets

- Metacharacters inside character sets are already escaped.

- Do not need to escape them again

- `/h[abc.xyz]t/` matches

My_hat_is_not_hot_but_is_h.t

- Exceptions

] - ^ \

- `/[[\]]/` matches

[]_brackets_rule!_Down_with_parentheses!

However, to avoid a future warning (in python) you should also escape the opening square bracket also, i.e., `/\[[\]]/`

Shorthand Characters Sets

Shorthand	Meaning	Equivalent
<code>\d</code>	Digit	<code>[0-9]</code>
<code>\w</code>	Word character	<code>[A-Za-z0-9_]</code>
<code>\s</code>	Whitespace	<code>[\t\r\n]</code>
<code>\D</code>	Not a digit	<code>[^0-9]</code>
<code>\W</code>	Not a word character	<code>[^A-Za-z0-9_]</code>
<code>\S</code>	Not a whitespace	<code>[^ \t\r\n]</code>

- Underscore is a word character, but hyphen is not.
- `/\s\d\d\d\d\s/` matches
 Reading 1984 in 1984 was cool only in 1984.
 (Arrows point to the spaces between the words)
- `/\s\w\w\w\w\s/` matches
 Reading 1984 in 1984 was cool only in 1984.
 (Arrows point to the spaces between the words)
- Note: While `/[^\d]/` is same as `/[\D]/`, and `/[^\s]/` is same as `/[\S]/`, however `/[^\d\s]/` is not the same as `/[\D\S]/`

Repetition Metacharacters

Metacharacter	Meaning
*	Preceding item (character or expression) zero or more times
+	Preceding item one or more times
?	Preceding item zero or one time

- `/apples*/` matches

apple, apples, applesss, applesss5s

(Note the greedy matching)

- `/apples+/` matches

apple, apples, applesss, applesss5s

(Again greedy matching)

- `/apples?/` matches

apple, apples, applesss, applesss5s

- `/\d\d\d\d\d*/` matches

1, 12, 123, 1234, 12345, 123456

Quantified Repetition

Metacharacter	Meaning
<code>{n}</code>	<i>n</i> occurrences of previous item
<code>{m, n}</code>	From <i>m</i> to <i>n</i> occurrences of previous item
<code>{m, }</code>	At least <i>m</i> occurrences of previous item
<code>{, n}</code>	At most <i>n</i> occurrences of previous item

- `/\d{0, }/` is same as `/\d*/`
- `/\d{1, }/` is same as `/\d+ /`
- `/A{1, 2} /` matches one or two “A” so what happened here?

`A_bonds, AA_bonds, AAA_bonds`

(In the python code that I used to generate examples I used *finditer* which performs multiple matches and so the three “A” are matched by two “A” and one “A”. Remember regex is greedy and eager)

Greedy Expressions

- Standard repetition qualifiers greedy — tries to match the longest possible string.
- However, it prioritizes eager over greedy — so will be less greedy in order to make a successful match.
- Consider applying the regex `/.+\.jpg/` to `filename.jpg`
 - The regex `/.+/` matches `filename.jpg` and `filename.png`
 - The `+/` is greedy but rewinds or backtracks so that “.jpg” is matched by rest of the expression.
- The regex gives back as little as possible to make match.
For example, `/.*[0-9]+/` matches `Page_666`
 - where `/.*/` matches “Page_66” and `/[0-9]+/` matches “6”.

Lazy Expressions

?

- Lazy Expression Metacharacter

- Switches the previous repetition operator from greedy to lazy strategy.

Greedy — match as much as possible before giving control to next expression part.

Lazy — match as little as possible before giving control to next expression part.

- Both defer to overall match (i.e. backtrack/roll forward)
- neither strategy is always faster/more efficient.

- Note **?** is also a repetition metacharacter (zero or one time). How do we know which role it is playing? — context.

Examples

- `/\w*?\d{3}/` matches

AA12_ AA123_ BBB12D0000

- `/.{4,8}?\-.{4,8}/` matches

AAAAAA-AAAA_ BBBB-BBBBBB

- `/.{4,8}\-.{4,8}?/` matches

AAAAAA-AAAA_ BBBB-BBBBBB

Strategies for Efficient Regex Repetition

General principle

Efficient matching \Rightarrow less backtracking \Rightarrow faster results.

Strategies

- Specify the quantity of repeated expressions — the more restrictive the better:
 - `/+/` is faster than `/*`.
 - `/.{4}/` and
 - `/.{2..7}/` are even faster.
- Narrow scope of ranges — the narrower the better.
 - Replace `/.+/` with `/[A-Za-z]+/`
- Provide clearer starting and ending points
 - Replace `<.+>/` with `<[^>]+>/`

Grouping Metacharacter

()

- Grouping metacharacters

- Apply repetition operation to a group
- Make expressions more readable (for humans)
- Captures a group for use in matching and replacing
- Cannot be used inside a character set.

Examples

- `/C (GT) +A/` matches

CA_CGTA_CGTA_CGTGTGTA_CGTGTGA

↑ ↑ ↑ ↑

- `/ (in)?dependent /` matches

independent_or_dependent

↑ ↑

Alternation Metacharacter



- Alternation metacharacter — OR operator
 - Either match expression on the left or match expression on the right
 - Ordered, left most expression gets precedence
 - Multiple options can be daisy-chained
 - Can group (using parenthesis) alternation expressions to improve readability
 - Alternation expressions can be nested

Examples

- `/apples|oranges|grapes/` matches
 I_like_apples_and_oranges_but_not_grapes
 (Arrows point from the red text 'apples', 'oranges', and 'grapes' to the vertical bar in the regex.)
- `/(AA|BB|(CC|\d)){2,4}/` matches
 DAA3CCBBEECBB3AACCBB
 (Arrows point from the red text '3' and '3' to the vertical bar in the regex.)
 (First matched alternation does not affect the next matches.)

Start and End Anchors

Metacharacter	Meaning
<code>^</code>	Start of a string/line
<code>\$</code>	End of a string/line
<code>\b</code>	Word boundary

- Anchors reference to a position not a character \Rightarrow have zero width
- Word boundary conditions
 - Before the first word character in the string
 - After the last word character in the string
 - Between a word character and a non-word character
 - Recall: word characters are `/ [A-Za-z0-9_] /`
- `/\b\w+\b/` matches

Sticks_and_stones_can_break_my_bones

(Note spaces are not matched)

Backreferences

\1 \2 ... \9

- Group expressions are captured
- Store the matched text portion that corresponds to the group expression.
 - For example. `/ (W\d{8}) /` matches `My_id_is_W66600666` and stores “W66600666” in `\1`.
 - Stored the matched text, not the expression.
- Can be used in same expression as the group
- Can be accessed after the match is complete (see regex object in python)
- Cannot be used inside character classes.
- Groups are captured automatically, but if you don't want[‡] to capture a group then start group with `?:`
 For example, replace `/ (\w+) /` with `/ (?: \w+) /`

[‡]Why? It is faster and you can only capture 9 (or 99 on some systems) groups.

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Example 4

Problem 4

Find all instances of the word “the” in the text.

“The_thesis_title_is_’The_tithe_of_the_Theron.’ ”

- /the/

The_thesis_title_is_’The_tithe_of_the_Theron.’

Fails to match “The” and incorrectly matches parts of words.

- /[Tt]he/

The_thesis_title_is_’The_tithe_of_the_Theron.’

... getting there, but we are still matching parts of words ...

- /\b[Tt]he\b/

The_thesis_title_is_’The_tithe_of_the_Theron.’

Done

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Find all instances of the word “the” in the text.

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The_thesis_title_is_’The_tithe_of_the_Theron.’

Fails to match “The” and incorrectly matches parts of words.

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The_thesis_title_is_’The_tithe_of_the_Theron.’

... getting there, but we are still matching parts of words ...

- /\b[Tt]he\b/

The_thesis_title_is_’The_tithe_of_the_Theron.’

Done

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Fails to match “The” and incorrectly matches parts of words.

- `/[Tt]he/`

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... getting there, but we are still matching parts of words ...

- `/\b[Tt]he\b/`

The_thesis_title_is_’The_tithe_of_the_Theron.’

Done

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... getting there, but we are still matching parts of words ...

- /\b[Tt]he\b/

The_thesis_title_is_’The_tithe_of_the_Theron.’

Done

Example 5 — Matching IP (IPV4) addresses

- `/\b\d+\.\d+\.\d+\.\d+\b/`

192.168.1.1 64.16.83.133 0.0.0.0 0.00 999.0.0.0 2545.0.0.0

Need to limit number of digits

- `/\b\d{1,3}\.\d{1,3}\.\d{1,3}\.\d{1,3}\b/`

192.168.1.1 64.16.83.133 0.0.0.0 0.00 999.0.0.0 2545.0.0.0

What to do about numbers in range 256-299?

- Match numbers in range 250–255 using `/25[0-5]/`
- Match numbers in range 200–249 using `/2[0-4][0-9]/`
- Match numbers in range 100–199 using `/1[0-9][0-9]/`
- Match numbers in range 10–99 using `/[1-9][0-9]/`
- Match numbers in range 0-9 using `/[0-9]/`
- If we just match a single number (to save space) we then have regex

`/\b(25[0-5]|2[0-4][0-9]|1[0-9][0-9]|[1-9][0-9]|[0-9])\b/`

192 1 24 255 256 999 2545

Exercise: shorten this expression!

Example 5 — Matching IP (IPV4) addresses

- `/\b\d+\.\d+\.\d+\.\d+\b/`

192.168.1.1_64.16.83.133_0.0.0.0_0.00_999.0.0.0_2545.0.0.0

Need to limit number of digits

- `/\b\d{1,3}\.\d{1,3}\.\d{1,3}\.\d{1,3}\b/`

192.168.1.1_64.16.83.133_0.0.0.0_0.00_999.0.0.0_2545.0.0.0

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- If we just match a single number (to save space) we then have regex
`/\b(25[0-5]|2[0-4][0-9]|1[0-9][0-9]|[1-9][0-9]|[0-9])\b/`

192_1_24_255_256_999_2545

Exercise: shorten this expression!

Example 5 — Matching IP (IPV4) addresses

- `/\b\d+\.\d+\.\d+\.\d+\b/`

192.168.1.1_64.16.83.133_0.0.0.0_0.00_999.0.0.0_2545.0.0.0

Need to limit number of digits

- `/\b\d{1,3}\.\d{1,3}\.\d{1,3}\.\d{1,3}\b/`

192.168.1.1_64.16.83.133_0.0.0.0_0.00_999.0.0.0_2545.0.0.0

What to do about numbers in range 256-299?

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- Match numbers in range 0-9 using `/[0-9]/`
- If we just match a single number (to save space) we then have regex

`/\b(25[0-5]|2[0-4][0-9]|1[0-9][0-9]|[1-9][0-9]|[0-9])\b/`

192_1_24_255_256_999_2545

Exercise: shorten this expression!

Example 6 — Matching Binding Sites

Recall the DNA binding pattern:



A suitable regular expression is

$/ [AG] \{ 3 \} CATG [TC] \{ 4 \} [AG] \{ 2 \} C [AT] TG [CT] [CG] [TC] /$

Examples

- ...AACTAGGCATGTCCTAACATGCCTAACT...
- ...AACTGGACATGTCCTAACATGCCCAACT...
- ...AACTGGACATGTCCTAACTTGTGCAACT...
- ...AACTAGGCATGTCCTAACATGCCAACT...
- ...AACTCGGCATGTCCTAACATGCCTAACT...

Outline

1. Motivation	2
2. Regular Expression Concepts	12
2.1. Metacharacters	14
2.2. Characters Sets	17
2.3. Repetition Expressions	22
2.4. Grouping and Alternation Expressions	27
2.5. Anchored Expressions	29
2.6. Capturing Groups and Back References	30
3. Examples	31
4. Python Implementation of Regular Expressions	35
5. Final Thoughts	38

The Python `re` Module

The python module, `re`, contains functions for manipulating regular expressions, and performing match and/or substitution. Main concepts:

- *Compiling Regular Expressions*

A regular expression needs to be compiled into a more efficient representation before use. You can explicitly compile using the function `re.compile`, python keeps a cache of previously compiled expressions.

- *Regular expression object*

Some `re` methods return an object on successful matching that not only contains the characters matched but also the start and end index, span, etc.

- *Storing regex as strings*

Python does not use forward-slash character to delimit regular expressions. Instead just treats them as ordinary strings and uses single and double quotes. To avoid metacharacters being interpreted by python use prefix `r` as in
`regex = r"[AG]3CATG[TC]4[AG]2C[AT]TG[CT][CG][TC]"`

Match vs Substitution

Matching

- `match(regex, string)`

Tries to match a regular expression at the beginning of the string. If successful, return a regular-expression object. Otherwise, returns `None`.

- `search(regex, string)`

Like `match` but not restricted to start of string.

- `findall(regex, string)`

Find all substrings of the string that match the regular expression. The function returns a list of all matching substrings.

- `finditer(regex, string)`

Find all substrings of the string that match the regular expression. The function returns a list of regular-expression objects.[§]

Substitution

- `re.sub(regex, replacement, string)`

Replace parts of a string that match a regular expression.

[§]See script `markup_re_examples.py`.

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Regular Expression Golf



— <http://xkcd.com/1313>

Example

Match elected US presidents but not opponents (unless they later won).

Match	obama, bush, clinton, regan, ... washington.
Don't match:	romney, mccain, gore,

Solution

A solution — works up to but not including Trump (still living in denial).

`bu|[rn]t|[coy]e|[mtg]a|j|iso|n|[hl]]|[ae]d|lev|sh|[lnd]|i|[po]o|ls`

Illegally Screening a Job Candidate

" [First name]! and pre/2 [last name] w/7
bush or gore or republican! or democrat! or charg!
or accus! or criticiz! or blam! or defend!
or iran contra or clinton or spotted owl
or florida recount or sex! or controversies! or fraud!
or investigat! or bankrupt! or layoff! or downsiz!
or PNTR or NAFTA or outsourc! or indict! or enron
or kerry or iraq or wmd! or arrest! or intox! or fired
or racis! or intox! or slur! or controversies! or abortion!
or gay! or homosexual! or gun! or firearm! "



— LexisNexis search string used by Monica Goodling
to illegally screen candidates for DOJ positions

www.justice.gov/oig/special/s0807/final.pdf

(Not all Republican misdeeds were under Trump!)

WHENEVER I LEARN A
NEW SKILL I CONCOCT
ELABORATE FANTASY
SCENARIOS WHERE IT
LETS ME SAVE THE DAY.

OH NO! THE KILLER
MUST HAVE FOLLOWED
HER ON VACATION!



BUT TO FIND THEM WE'D HAVE TO SEARCH
THROUGH 200 MB OF EMAILS LOOKING FOR
SOMETHING FORMATTED LIKE AN ADDRESS!



IT'S HOPELESS!

EVERYBODY STAND BACK.



I KNOW REGULAR
EXPRESSIONS.

