l3regex 模块

TEX 中的正则表达式

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目　录

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l3regex 模块提供正则表达式测试、子匹配提取、分割和替换，全部作用于记号列表。正则表达式的语法主要是 PCRE 语法的子集（并且非常接近 POSIX），但由于 TEX 操作的是记号而不是字符，因此有一些附加的功能。由于性能原因，仅实现了有限的功能集。特别地，不支持反向引用。

让我们给出一些示例。在

```
\tl_set:Nn \l_my_tl { That~cat. }
\regex_replace_once:nnN { at } { is } \l_my_tl
```

记号列表变量 `\l_my_tl` 存储文本 “`This cat.`”，其中第一个 “`at`” 被替换为 “`is`”。一个更复杂的例子是用于强调每个单词并在其后添加逗号的模式：

```
\regex_replace_all:nnN { \w+ } { \c{emph}\cB\{ \0 \cE\} , } \l_my_tl
```

`\w` 序列表示任何“word”字符，而 `+` 表示 `\w` 序列应重复尽可能多次（至少一次），因此匹配输入记号列表中的一个单词。在替换文本中，`\0` 表示完全匹配（这里是一个单词）。通过 `\c{emph}` 插入 `\emph` 命令，并将其参数 `\0` 放在大括号 `\cB\{` 和 `\cE\}` 之间。

如果要多次使用正则表达式，可以编译一次，并使用 `\regex_set:Nn` 将其存储在正则表达式变量中。例如，

```
\regex_new:N \l_foo_regex
\regex_set:Nn \l_foo_regex { \c{begin} \cB. (\c[^BE].*) \cE. }
```

在 `\l_foo_regex` 中存储一个正则表达式，该表达式匹配环境的起始标记：`\begin`，后跟一个起始组记号（`\cB.`），然后是任意数量的既不是起始组记号也不是结束组记号字符记号的记号（`\c[^BE].*`），最后是结束组记号（`\cE.`）。如下一节所述，括号 “捕获” 了 `\c[^BE].*` 的结果，从而在进行替换时让我们能够访问环境的名称。

1 正则表达式的语法

1.1 正则表达式示例

我们从一些示例开始，并鼓励读者对这些正则表达式应用 `\regex_show:n`。

- `Cat` 匹配以此方式大写的单词 “Cat”，但也匹配单词 “Cattle” 的开头：使用 `\bCat\b` 仅匹配完整的单词。

- `[abc]` 匹配字母 “a”、“b”、“c” 中的一个；模式 `(a|b|c)` 匹配相同的三个可能的字母（但请参阅下面的子匹配的讨论）。

- `[A-Za-z]*` 匹配任意数量（由于量词 `*`）的拉丁字母（没有重音）。

- `\c{[A-Za-z]*}` 匹配由拉丁字母组成的控制序列。

- `\_[^\_]*\_` 匹配下划线，除下划线外的任意数量字符，和另一个下划线；这等效于 `\_.*?\_`，其中 `.` 匹配任意字符，懒惰量词 `*?` 表示尽可能匹配少的字符，从而避免匹配下划线。

- `[\+\-]?\d+` 匹配带有最多一个符号的显式整数。

- `[\+\-\␣]*\d+\␣*` 匹配带有任意数量 + 和 − 符号的显式整数，允许空格，除了在尾数内，且被空格包围。

- `[\+\-\␣]*(\d+|\d*\.\d+)\␣*` 匹配显式整数或小数；使用 `[.,]` 而不是 `\.` 允许逗号作为小数点。

- `[\+\-\␣]*(\d+|\d*\.\d+)\␣*((?i)pt|in|[cem]m|ex|[bs]p|[dn]d|[pcn]c)\␣*` 匹配任何 TeX 知道的显式尺寸，其中 `(?i)` 表示对待小写和大写字母相同。

- `[\+\-\␣]*((?i)nan|inf|(\d+|\d*\.\d+)(\␣*e[\+\-\␣]*\d+)?)\␣*` 匹配显式浮点数或特殊值 `nan` 和 `inf`（允许符号和空格）。

- `[\+\-\␣]*(\d+|\cC.)\␣*` 匹配显式整数或控制序列（不检查是否是整数变量）。

- `\G.*?\K` 在正则表达式开头匹配并丢弃（由于 `\K`）前一个匹配的结尾（`\G`），以及由正则表达式的其余部分匹配的内容；在 `\regex_replace_all:nnN` 中很有用，当目标是以比 `\regex_extract_all:nnN` 更精细的方式提取匹配项或子匹配项时。

尽管不可能让正则表达式仅匹配整数表达式，但是

```
[\+\-\(]*\d+\)*([\+\-*/][\+\-\(]*\d+\)*)*
```

匹配所有有效的整数表达式（仅由显式整数制成）。应该跟随进一步的测试。

1.2　正则表达式中的字符

大多数字符与它们自己完全匹配，具有任意类别码。一些字符是特殊的，必须用反斜杠转义（例如，`\*` 匹配星号字符）。一些反斜杠-字母形式的转义序列也具有特殊含义（例如 `\d` 匹配任何数字）。一般规则是，

- 每个字母数字字符（`A`–`Z`、`a`–`z`、`0`–`9`）与其自身完全匹配，不应转义，因为 `\A`、`\B` 等具有特殊含义；

- 非字母数字可打印 ASCII 字符应始终（并且应该）转义：其中许多字符具有特殊含义（例如，使用 `\(`、`\)`、`\?`、`\.`、`\^`）；

- 空格应始终转义（即使在字符类中）；
- 其他任何字符可以转义，也可以不转义，都没有任何效果：两个版本都完全匹配该字符。

请注意，这些规则与许多非字母数字字符在正常类别码下很难输入到 TEX 中的事实相吻合。例如，`\\abc\%` 匹配字符 `\abc%`（具有任意类别码），但不匹配控制序列 `\abc` 后跟一个百分号字符。可以使用 `\c{`⟨*regex*⟩`}` 语法（见下文）来匹配控制序列。

任何特殊字符出现在其特殊行为无法应用的地方时，将匹配自身（例如，在字符串开头出现的量词），并提出警告。

字符。

`\x{hh…}` 具有十六进制代码 `hh…` 的字符

`\xhh` 具有十六进制代码 `hh` 的字符

`\a` 警报（十六进制 07）

`\e` 转义（十六进制 1B）

`\f` 进纸换页（十六进制 0C）

`\n` 换行（十六进制 0A）

`\r` 回车（十六进制 0D）

`\t` 水平制表符（十六进制 09）

1.3 字符类

字符属性。

`.` 单个句点匹配任何记号。

`\d` 任何十进制数字。

`\h` 任何水平空白字符，等同于 `[\ \^^I]`：空格和制表符。

`\s` 任何空格字符，等同于 `[\ \^^I\^^J\^^L\^^M]`

`\v` 任何垂直空白字符，等同于 `[\^^J\^^K\^^L\^^M]`。注意 `\^^K` 是垂直空白，但不是空格，以兼容 Perl。

`\w` 任何单词字符，即字母数字和下划线，等同于明确的类 `[A-Za-z0-9\_]`

`\D` 任何非 `\d` 匹配的记号。

\H 任何非 \h 匹配的记号。

\N 任何非 \n 字符（十六进制 0A）的记号。

\S 任何非 \s 匹配的记号。

\V 任何非 \v 匹配的记号。

\W 任何非 \w 匹配的记号。

其中，.、\D、\H、\N、\S、\V 和 \W 匹配任意控制序列。
字符类精确匹配主题中的一个记号。

[...] 正向字符类。匹配指定的任何记号。

[^...] 负向字符类。匹配指定字符之外的任何记号。

x-y 在字符类中，表示一个范围（可以与转义字符一起使用）。

[:⟨*name*⟩:] 在字符类中（另一组括号），表示 POSIX 字符类 ⟨*name*⟩，可以是 alnum、alpha、ascii、blank、cntrl、digit、graph、lower、print、punct、space、upper、word 或 xdigit。

[:^⟨*name*⟩:] 负向 POSIX 字符类。

例如，[a-oq-z\cC.] 匹配任何小写拉丁字母，除了 p，以及控制序列（见下文对 \c 的描述）。

在字符类中，只有 [、^、-、]、\ 和空格是特殊的，应该被转义。其他非字母数字字符仍可被转义而不会受到影响。在字符类中支持匹配单个字符的任何转义序列（\d、\D、等）。如果第一个字符是 ^，则字符类的含义被反转；在范围中的任何其他位置出现的 ^ 都不是特殊的。如果第一个字符（可能是在一个领先的 ^ 之后）是]，则不需要转义，因为在那里结束范围将使其为空。字符的范围可以用 - 表示，例如，[\D 0-5] 和 [^6-9] 是等价的。

1.4 结构：替代、分组、重复

量词（重复）。

? 0 或 1，贪婪模式。

?? 0 或 1，懒惰模式。

* 0 或多次，贪婪模式。

*? 0 或多次，懒惰模式。

+ 1 或多次，贪婪模式。

+? 1 或多次，懒惰模式。

{n} 恰好 n 次。

{n,} n 次或更多，贪婪模式。

{n,}? n 次或更多，懒惰模式。

{n, m} 至少 n 次，最多 m 次，贪婪模式。

{n, m}? 至少 n 次，最多 m 次，懒惰模式。

对于贪婪量词，正则表达式代码将首先尝试尽可能多的重复匹配，而对于懒惰量词，它将首先尝试尽可能少的重复匹配。

替代和捕获分组。

A|B|C A、B 或 C 中的任意一个，首先尝试匹配 A。

(…) 捕获分组。

(?:…) 非捕获分组。

(?|…) 非捕获分组，每个替代中都重置捕获分组编号。下一个分组将用第一个未使用的分组编号进行编号。

捕获分组是提取关于匹配的信息的一种方法。带括号的组按照其打开括号的顺序编号，从 1 开始。可以使用例如 \regex_extract_once:nnNTF 将这些组的内容提取并存储在一系列记号列表中。

\K 转义序列将匹配的开始位置重置为记号列表中的当前位置。这仅影响作为完整匹配报告的内容。例如，

```
\regex_extract_all:nnN { a \K . } { a123aaxyz } \l_foo_seq
```

的结果是 \l_foo_seq 包含项 {1} 和 {a}：真正的匹配是 {a1} 和 {aa}，但它们被使用 \K 截断。\K 命令不影响捕获分组，例如，

```
\regex_extract_once:nnN { (. \K c)+ \d } { acbc3 } \l_foo_seq
```

的结果是 \l_foo_seq 包含项 {c3} 和 {bc}：真正的匹配是 {acbc3}，其中第一个子匹配是 {bc}，但 \K 重置匹配的开始位置为它出现的最后位置。

1.5 匹配确切的记号

\c 转义序列允许测试记号的类别码，并匹配控制序列。每个字符类别由单个大写字母表示：

- C 表示控制序列；
- B 表示开始组记号；
- E 表示结束组记号；
- M 表示数学换位符；
- T 表示对齐制表符记号；
- P 表示宏参数记号；
- U 表示上标记号（上）；
- D 表示下标记号（下）；
- S 表示空格；
- L 表示字母；
- O 表示其他；以及
- A 表示活动字符。

\c 转义序列的使用如下。

\c{⟨*regex*⟩} 一个控制序列,其控制序列名称匹配 ⟨*regex*⟩,锚定在开头和结尾,因此 \c{begin} 精确匹配 \begin，而不匹配其他任何内容。

\cX 适用于下一个对象，可以是字符、转义字符序列（如 \x{0A}）、字符类或组，并强制该对象只匹配类别为 X 的记号（其中 X 为 CBEMTPUDSLOA 中的任意一个）。例如，\cL[A-Z\d] 匹配大写字母和类别为字母的数字，\cC. 匹配任何控制序列，\cO(abc) 匹配类别为其他的 abc。[1]

\c[XYZ] 适用于下一个对象，并强制它只匹配类别为 X、Y 或 Z 的记号（其中每个都是 CBEMTPUDSLOA 中的任意一个）。例如，\c[LSO](..) 匹配两个类别为字母、空格或其他的记号。

\c[^XYZ] 适用于下一个对象，并阻止它匹配类别为 X、Y 或 Z 的任何记号（其中每个都是 CBEMTPUDSLOA 中的任意一个）。例如，\c[^O]\d 匹配类别为其他的数字。

[1] 最后一个示例还捕获了“abc”作为正则表达式组；要避免这种情况，请使用非捕获组 \cO(?:abc)。

类别码测试可用于类中；例如，[\c0\d \c[LO][A-F]] 匹配 TEX 认为的十六进制数字，即类别为其他的数字，或类别为字母或其他的大写字母。在受到类别码测试影响的组内，嵌套测试可以覆盖外部测试；例如，\cL(ab\c0\cd) 匹配所有字符都是字母类别的 abcd，除了 * 的类别是其他。

\u 转义序列允许将记号列表的内容直接插入正则表达式或替换中，无需转义特殊字符。即，\u{⟨*var name*⟩} 精确匹配变量 \⟨*var name*⟩ 的内容（包括字符码和类别码），这是通过在编译正则表达式时应用 \exp_not:v {⟨*var name*⟩} 获得的。在 \c{...} 控制序列匹配中，\u 转义序列仅展开其参数一次，实际上执行 \tl_to_str:v。支持量词。

\ur 转义序列允许将 regex 变量的内容插入较大的正则表达式。例如,A\ur{l_tmpa_regex}D 匹配由匹配正则表达式 \l_tmpa_regex 的内容分隔的记号 A 和 D。这相当于将非捕获组包围在 \l_tmpa_regex 周围，并且 \l_tmpa_regex 中包含的任何组都会转换为非捕获组。支持量词。

例如，如果 \l_tmpa_regex 的值为 B|C，那么 A\ur{l_tmpa_regex}D 等效于 A(?:B|C)D（匹配 ABD 或 ACD），而不是 AB|CD（匹配 AB 或 CD）。要获得后者的效果，最简单的方法是直接使用 TEX 的展开机制：如果 \l_mymodule_BC_tl 包含 B|C，那么以下两行显示相同的结果：

```
\regex_show:n { A \u{l_mymodule_BC_tl} D }
\regex_show:n { A B | C D }
```

1.6 杂项

锚点和简单断言。

\b 单词边界：前一个记号由 \w 匹配，下一个由 \W 匹配；或者相反。为此，将记号列表的两端视为 \W。

\B 非单词边界：在两个 \w 记号或两个 \W 记号之间（包括边界）。

^ 或 \A 主题记号列表的开始。

$, \Z 或 \z 主题记号列表的结尾。

\G 当前匹配的开始。仅在多次匹配的情况下与 ^ 不同:例如,\regex_count:nnN { \G a } { aaba 得到 2，但将 \G 替换为 ^ 将导致 \l_tmpa_int 包含值 1。

选项 (?i) 使匹配不区分大小写（将 A–Z 和 a–z 视为等效，尚不支持 Unicode 大小写转换）。这适用于它所在的组直到结束，并可使用 (?-i) 还原。例如，在 (?i)(a(?-i)b|c)d 中，字母 a 和 d 受到 i 选项的影响。范围和类中的字符被单独

影响：(?i)[\?-B] 等效于 [\?@ABab]（与较大的类 [\?-b] 不同），(?i)[^aeiou] 匹配任何不是元音的字符。i 选项对于 \c{...}、\u{...}、字符属性或字符类等没有任何影响，例如在 (?i)\u{l_foo_tl}\d\d[[:lower:]] 中根本不起作用。

2 替换文本的语法

正则表达式中描述的大多数功能在替换文本中没有意义。反斜杠引入各种特殊结构，下面将进一步描述：

- \0 表示整个匹配；
- \1 表示由第一个（捕获）组 (...) 匹配的子匹配；类似地，\2、…、\9 和 \g{⟨*number*⟩}
- \␣ 插入一个空格（未转义的情况下忽略空格）；
- \a、\e、\f、\n、\r、\t、\xhh、\x{hhh} 对应于正则表达式中的单个字符；
- \c{⟨*cs name*⟩} 插入一个控制序列；
- \c⟨*category*⟩⟨*character*⟩（见下文）；
- \u{⟨*tl var name*⟩} 将变量 ⟨*tl var*⟩ 的内容直接插入替换文本，无需转义特殊字符。

除反斜杠和空格之外的字符直接插入结果中（但由于首先将替换文本转换为字符串，因此也应转义对于 TEX 而言是特殊的字符，例如使用 \#)。非字母数字字符始终可以安全地使用反斜杠进行转义。例如，

```
\tl_set:Nn \l_my_tl { Hello,~world! }
\regex_replace_all:nnN { ([er]?l|o) . } { (\0--\1) } \l_my_tl
```

导致 \l_my_tl 包含 H(ell--el)(o,--o) w(or--o)(ld--l)!

子匹配的编号按照捕获组的开放括号在要匹配的正则表达式中出现的顺序进行。如果捕获组少于 n 个，或者捕获组出现在未用于匹配的替代方案中，则第 n 个子匹配为空。如果捕获组在匹配期间多次匹配（由于量词），则在替换文本中仅使用最后一次匹配。子匹配始终保持与原始记号列表相同的类别码。

默认情况下，替换插入的字符的类别码由替换时的主要类别码制度确定，有两个例外：

- 通过 \␣、\x20 或 \x{20} 插入的空格字符（字符码为 32）无论当前的类别码制度如何，其类别码始终为 10；

- 如果类别码为 0（转义）、5（换行符）、9（忽略）、14（注释）或 15（无效），则替换时将其替换为 12（其他）。

转义序列 \c 允许插入具有任意类别码的字符，以及控制序列。

\cX(…) 产生类别为 X 的字符 "…"，其中 X 必须是正则表达式中的 CBEMTPUDSLOA 之一。括号对于单个字符（可能是转义序列）是可选的。嵌套时，应用最内层的类别码，例如 \cL(Hello\cS\ world)! 会产生标准类别码的此文本。

\c{⟨*text*⟩} 插入 csname 为 ⟨*text*⟩ 的控制序列。⟨*text*⟩ 可能包含对子匹配 \0、\1 等的引用，如下例所示。

转义序列 \u{⟨*var name*⟩} 允许将变量 ⟨*var name*⟩ 的内容直接插入替换文本，更容易控制类别码。在 \c{…} 和 \u{…} 结构中嵌套时，\u 和 \c 转义序列执行 \tl_to_str:v，即提取控制序列的值并将其转换为字符串。匹配还可在 \c 和 \u 的参数中使用。例如，

```
\tl_set:Nn \l_my_one_tl { first }
\tl_set:Nn \l_my_two_tl { \emph{second} }
\tl_set:Nn \l_my_tl { one , two , one , one }
\regex_replace_all:nnN { [^,]+ } { \u{l_my_\0_tl} } \l_my_tl
```

结果为 \l_my_tl 包含 first,\emph{second},first,first。

正则表达式替换还是一个方便的方法，用于生成具有任意类别码的记号列表。例如

```
\tl_clear:N \l_tmpa_tl
\regex_replace_all:nnN { } { \cU\% \cA\~ } \l_tmpa_tl
```

导致 \l_tmpa_tl 包含类别码为 7（上标）的百分号字符和活动中划线字符。

3 预编译正则表达式

如果要多次使用正则表达式，最好是编译一次，而不是每次使用正则表达式时都编译。编译后的正则表达式存储在一个变量中。所有 l3regex 模块的函数都可以将其正则表达式参数作为显式字符串或编译后的正则表达式给出。

\regex_new:N
New: 2017-05-26

\regex_new:N ⟨*regex var*⟩

创建一个新的 ⟨*regex var*⟩，如果名称已被使用则引发错误。该声明是全局的。初始时，⟨*regex var*⟩ 被设置为永远不匹配。

\regex_set:Nn
\regex_gset:Nn

New: 2017-05-26

\regex_set:Nn ⟨*regex var*⟩ {⟨*regex*⟩}

在 ⟨*regex var*⟩ 中存储 ⟨正则表达式⟩ 的编译版本。对于 \regex_set:Nn，赋值是局部的；对于 \regex_gset:Nn，是全局的。例如，此函数可以用作

```
\regex_new:N \l_my_regex
\regex_set:Nn \l_my_regex { my\ (simple\ )? reg(ex|ular\ expression) }
```

\regex_const:Nn

New: 2017-05-26

\regex_const:Nn ⟨*regex var*⟩ {⟨*regex*⟩}

创建一个新的常量 ⟨*regex var*⟩，如果名称已被使用则引发错误。⟨*regex var*⟩ 的值被全局设置为 ⟨正则表达式⟩ 的编译版本。

\regex_show:N
\regex_show:n
\regex_log:N
\regex_log:n

New: 2021-04-26
Updated: 2021-04-29

\regex_show:n {⟨*regex*⟩}
\regex_log:n {⟨*regex*⟩}

在终端显示或写入日志文件（分别）l3regex 如何解释 ⟨*regex*⟩。例如，\regex_show:n {\A X|Y} 显示

```
+-branch
  anchor at start (\A)
  char code 88 (X)
+-branch
  char code 89 (Y)
```

表明锚 \A 仅适用于第一分支：第二分支未锚定到匹配的开始。

4 匹配

所有正则表达式函数都有 :n 和 :N 两种变体。前者需要一个“标准”正则表达式，而后者需要由 \regex_set:Nn 生成的编译表达式。

\regex_match:nn*TF*
\regex_match:nV*TF*
\regex_match:Nn*TF*
\regex_match:NV*TF*

New: 2017-05-26

\regex_match:nnTF {⟨*regex*⟩} {⟨*token list*⟩} {⟨*true code*⟩} {⟨*false code*⟩}

测试 ⟨正则表达式⟩ 是否与 ⟨*token list*⟩ 的任何部分匹配。例如，

```
\regex_match:nnTF { b [cde]* } { abecdcx } { TRUE } { FALSE }
\regex_match:nnTF { [b-dq-w] } { example } { TRUE } { FALSE }
```

在输入流中留下 TRUE 然后 FALSE。

\regex_count:nnN
\regex_count:nVN
\regex_count:NnN
\regex_count:NVN

New: 2017-05-26

\regex_count:nnN {⟨*regex*⟩} {⟨*token list*⟩} ⟨*int var*⟩

在当前 TeX 组级别内，将 ⟨*int var*⟩ 设置为 ⟨正则表达式⟩ 在 ⟨*token list*⟩ 中出现的次数。搜索从找到最左边最长的匹配开始，尊重贪婪和懒惰（非贪婪）运算符。然后，搜索从前一匹配的最后一个字符之后的字符开始，直到达到 token list 的末尾。在正则表达式可以匹配空 token list 的情况下，防止无限循环：在每对字符之间计数一次匹配。例如，

```
\int_new:N \l_foo_int
\regex_count:nnN { (b+|c) } { abbababcbb } \l_foo_int
```

的结果是 \l_foo_int 的值为 5。

\regex_match_case:nn
\regex_match_case:nn*TF*

New: 2022-01-10

\regex_match_case:nnTF
  {
    {⟨*regex*$_1$⟩} {⟨*code case*$_1$⟩}
    {⟨*regex*$_2$⟩} {⟨*code case*$_2$⟩}
    …
    {⟨*regex*$_n$⟩} {⟨*code case*$_n$⟩}
  } {⟨*token list*⟩}
  {⟨*true code*⟩} {⟨*false code*⟩}

确定在 ⟨*token list*⟩ 中的最早位置哪个 ⟨正则表达式⟩ 匹配，并在输入流中留下相应的 ⟨*code*$_i$⟩，后跟 ⟨*true code*⟩。如果多个 ⟨*regex*⟩ 在同一点开始匹配，则选择列表中的第一个，并丢弃其他的。如果没有任何 ⟨*regex*⟩ 匹配，则在输入流中留下 ⟨*false code*⟩。每个 ⟨*regex*⟩ 都可以是正则表达式变量或显式正则表达式。

具体而言，对于 ⟨*token list*⟩ 中的每个起始位置，依次搜索 ⟨*regex*⟩。如果其中一个匹配，则使用相应的 ⟨*code*⟩，并丢弃其他一切；如果在给定位置没有 ⟨*regex*⟩ 匹配，则尝试下一个起始位置。如果在 ⟨*token list*⟩ 的任何位置都没有任何 ⟨*regex*⟩ 匹配，则在输入流中什么都不留下。请注意，这与嵌套的 \regex_match:nnTF 语句不同，因为在每个位置尝试匹配所有 ⟨*regex*⟩，而不是在移动到 ⟨*regex*$_2$⟩ 之前尝试匹配 ⟨*regex*$_1$⟩。

5 子匹配提取

\regex_extract_once:nnN
\regex_extract_once:nVN
\regex_extract_once:nnNTF
\regex_extract_once:nVNTF
\regex_extract_once:NnN
\regex_extract_once:NVN
\regex_extract_once:NnNTF
\regex_extract_once:NVNTF

New: 2017-05-26

\regex_extract_once:nnN {⟨*regex*⟩} {⟨*token list*⟩} ⟨*seq var*⟩
\regex_extract_once:nnNTF {⟨*regex*⟩} {⟨*token list*⟩} ⟨*seq var*⟩ {⟨*true code*⟩} {⟨*false code*⟩}

在 ⟨*token list*⟩ 中找到 ⟨正则表达式⟩ 的第一个匹配项。如果存在匹配项，将匹配项存储为 ⟨*seq var*⟩ 的第一项，其余项是捕获组的内容，按其开括号的顺序。局部赋值给 ⟨*seq var*⟩。如果没有匹配项，则清除 ⟨*seq var*⟩。测试版本如果找到匹配项，则将 ⟨*true code*⟩ 插入输入流，否则插入 ⟨*false code*⟩。

例如，假设您键入

```
\regex_extract_once:nnNTF { \A(La)?TeX(!*)\Z } { LaTeX!!! } \l_foo_seq
  { true } { false }
```

那么正则表达式（在开始处用 \A 锚定，在结束处用 \Z 锚定）必须匹配整个 token list。第一个捕获组，(La)?，匹配 La，第二个捕获组，(!*)，匹配 !!!。因此，\l_foo_seq 的结果包含项 {LaTeX!!!}，{La} 和 {!!!}，并在输入流中留下 true 分支。注意，\l_foo_seq 的第 n 项，使用 \seq_item:Nn 获取，对应于函数 \regex_replace_once:nnN 等中编号为 $(n-1)$ 的子匹配。

\regex_extract_all:nnN
\regex_extract_all:nVN
\regex_extract_all:nnNTF
\regex_extract_all:nVNTF
\regex_extract_all:NnN
\regex_extract_all:NVN
\regex_extract_all:NnNTF
\regex_extract_all:NVNTF

New: 2017-05-26

\regex_extract_all:nnN {⟨*regex*⟩} {⟨*token list*⟩} ⟨*seq var*⟩
\regex_extract_all:nnNTF {⟨*regex*⟩} {⟨*token list*⟩} ⟨*seq var*⟩ {⟨*true code*⟩} {⟨*false code*⟩}

在 ⟨*token list*⟩ 中找到 ⟨正则表达式⟩ 的所有匹配项，并将所有子匹配信息存储在一个序列中（连接多个 \regex_extract_once:nnN 调用的结果）。局部赋值给 ⟨*seq var*⟩。如果没有匹配项，则清除 ⟨*seq var*⟩。测试版本如果找到匹配项，则将 ⟨*true code*⟩ 插入输入流，否则插入 ⟨*false code*⟩。例如，假设您键入

```
\regex_extract_all:nnNTF { \w+ } { Hello,~world! } \l_foo_seq
  { true } { false }
```

那么正则表达式匹配两次，生成的序列包含两个项 {Hello} 和 {world}，并在输入流中留下 true 分支。

\regex_split:nnN
\regex_split:nVN
\regex_split:nnN*TF*
\regex_split:nVN*TF*
\regex_split:NnN
\regex_split:NVN
\regex_split:NnN*TF*
\regex_split:NVN*TF*

New: 2017-05-26

\regex_split:nnN {⟨*regular expression*⟩} {⟨*token list*⟩} ⟨*seq var*⟩
\regex_split:nnNTF {⟨*regular expression*⟩} {⟨*token list*⟩} ⟨*seq var*⟩ {⟨*true code*⟩} {⟨*false code*⟩}

将 ⟨*token list*⟩ 拆分为一系列部分，由 ⟨正则表达式⟩ 的匹配项分隔。如果 ⟨正则表达式⟩ 具有捕获组，则它们匹配的 token lists 也存储为序列的项。局部赋值给 ⟨*seq var*⟩。如果找不到匹配项，生成的 ⟨*seq var*⟩ 以 ⟨*token list*⟩ 为其唯一项。如果 ⟨正则表达式⟩ 匹配空 token list，则将 ⟨*token list*⟩ 拆分为单个 token。测试版本如果找到匹配项，则将 ⟨*true code*⟩ 插入输入流，否则插入 ⟨*false code*⟩。例如，在

```
\seq_new:N \l_path_seq
\regex_split:nnNTF { / } { the/path/for/this/file.tex } \l_path_seq
  { true } { false }
```

之后，序列 \l_path_seq 包含项 {the}，{path}，{for}，{this} 和 {file.tex}，并在输入流中留下 true 分支。

6 替换

\regex_replace_once:nnN
\regex_replace_once:nVN
\regex_replace_once:nnN*TF*
\regex_replace_once:nVN*TF*
\regex_replace_once:NnN
\regex_replace_once:NVN
\regex_replace_once:NnN*TF*
\regex_replace_once:NVN*TF*

New: 2017-05-26

\regex_replace_once:nnN {⟨*regular expression*⟩} {⟨*replacement*⟩} ⟨*tl var*⟩
\regex_replace_once:nnNTF {⟨*regular expression*⟩} {⟨*replacement*⟩} ⟨*tl var*⟩ {⟨*true code*⟩} {⟨*false code*⟩}

在 ⟨*tl var*⟩ 的内容中搜索 ⟨正则表达式⟩，并用 ⟨替换⟩ 替换第一个匹配项。在 ⟨替换⟩ 中，\0 代表完整匹配，\1 代表第一个捕获组的内容，\2 代表第二个，以此类推。结果局部赋值给 ⟨*tl var*⟩。

\regex_replace_all:nnN
\regex_replace_all:nVN
\regex_replace_all:nnN*TF*
\regex_replace_all:nVN*TF*
\regex_replace_all:NnN
\regex_replace_all:NVN
\regex_replace_all:NnN*TF*
\regex_replace_all:NVN*TF*

New: 2017-05-26

\regex_replace_all:nnN {⟨*regular expression*⟩} {⟨*replacement*⟩} ⟨*tl var*⟩
\regex_replace_all:nnNTF {⟨*regular expression*⟩} {⟨*replacement*⟩} ⟨*tl var*⟩ {⟨*true code*⟩} {⟨*false code*⟩}

将 ⟨*tl var*⟩ 的内容中的 ⟨正则表达式⟩ 的所有匹配项都替换为 ⟨替换⟩，其中 \0 代表完整匹配，\1 代表第一个捕获组的内容，\2 代表第二个，以此类推。每个匹配项都是独立处理的，匹配项之间不能重叠。结果局部赋值给 ⟨*tl var*⟩。

```
\regex_replace_case_once:nN
\regex_replace_case_once:nNTF
New: 2022-01-10
```

```
\regex_replace_case_once:nNTF
  {
    {⟨regex₁⟩} {⟨replacement₁⟩}
    {⟨regex₂⟩} {⟨replacement₂⟩}
    …
    {⟨regexₙ⟩} {⟨replacementₙ⟩}
  } ⟨tl var⟩
  {⟨true code⟩} {⟨false code⟩}
```

将 `(?|`⟨*regex*$_1$⟩`|`…`|`⟨*regex*$_n$⟩`)` 的最早匹配项，用与之匹配的 ⟨*replacement*⟩ 替换，在输入流中留下 ⟨*true code*⟩。如果没有 ⟨*regex*⟩ 匹配，则不修改 ⟨*tl var*⟩，并在输入流中留下 ⟨*false code*⟩。每个 ⟨*regex*⟩ 可以作为 regex 变量或显式正则表达式给出。

具体而言，对于 ⟨*token list*⟩ 中的每个起始位置，按顺序搜索每个 ⟨*regex*⟩。如果其中一个匹配，则将其替换为与之对应的 ⟨*replacement*⟩，并从紧随此匹配（和替换）的位置开始重新搜索。这相当于使用 `\regex_match_case:nn` 检查哪个 ⟨*regex*⟩ 匹配，然后用 `\regex_replace_once:nnN` 执行替换。

\regex_replace_case_all:nN
\regex_replace_case_all:nNTF

New: 2022-01-10

```
\regex_replace_case_all:nNTF
  {
    {⟨regex₁⟩} {⟨replacement₁⟩}
    {⟨regex₂⟩} {⟨replacement₂⟩}
    …
    {⟨regexₙ⟩} {⟨replacementₙ⟩}
  } ⟨tl var⟩
  {⟨true code⟩} {⟨false code⟩}
```

将 ⟨*token list*⟩ 中所有 ⟨*regex*⟩ 的所有匹配项都替换为相应的 ⟨*replacement*⟩。每个匹配项都是独立处理的，匹配项之间不能重叠。结果局部赋值给 ⟨*tl var*⟩，并根据是否进行了替换留下 ⟨*true code*⟩ 或 ⟨*false code*⟩。

具体而言，对于 ⟨*token list*⟩ 中的每个起始位置，按顺序搜索每个 ⟨*regex*⟩。如果其中一个匹配，则将其替换为与之对应的 ⟨*replacement*⟩，并从紧随此匹配（和替换）的位置开始重新搜索。例如

```
\tl_set:Nn \l_tmpa_tl { Hello,~world! }
\regex_replace_case_all:nN
  {
    { [A-Za-z]+ } { ``\0'' }
    { \b } { --- }
    { . } { [\0] }
  } \l_tmpa_tl
```

结果是 \l_tmpa_tl 包含内容 ``Hello''---[,][␣]``world''---[!]。请特别注意，单词边界断言 \b 在单词开头没有匹配，因为情况 [A-Za-z]+ 在这些位置匹配。要更改这一点，可以简单地交换 \regex_replace_case_all:nN 参数中两个案例的顺序。

7 临时用的正则表达式

\l_tmpa_regex
\l_tmpb_regex

New: 2017-12-11

本地赋值的 Scratch 正则表达式。这些从未被内核代码使用，因此可安全用于任何 LaTeX3 定义的函数。但可能被其他非内核代码覆盖，因此仅用于短期存储。

\g_tmpa_regex
\g_tmpb_regex

New: 2017-12-11

全局赋值的 Scratch 正则表达式。这些从未被内核代码使用，因此可安全用于任何 LaTeX3 定义的函数。但可能被其他非内核代码覆盖，因此仅用于短期存储。

8 错误、缺陷、未来工作和其他可能性

现在需要完成以下任务。

- 以更有序的方式重写文档，或许添加一个 BNF?

更多的错误检查即将到来。

- 整理消息的使用。
- 在替换阶段进行更清晰的错误报告。
- 添加跟踪信息。
- 检测尝试使用反向引用和其他未实现语法的情况。
- 测试最大寄存器\c_max_register_int 的情况。
- 弄清楚\W和类似的匹配是否导致错误。可能更新\__regex_item_reverse:n。
- 空 cs 应该由\c{}匹配，而不是由\c{csname.?endcsname\s?}匹配。

代码改进即将到来。

- 将数组移动，使有用信息从位置 1 开始。
- 仅构建一次\c{...}。
- 在编译正则表达式时，使用左右状态堆栈的数组。
- __regex_action_free_group:n 是否仅用于贪婪的{n,}量词?(我认为不是。)
- 对于\u和断言的量词。
- 在匹配时，跟踪 curr_state 和 curr_submatches 的显式堆栈。
- 如果可能的话，在同一线程中重复使用状态时，终止其他子线程。
- 使用数组而不是\g__regex_balance_tl 来构建函数__regex_replacement_balance_one_match:n。
- 减少替代中的 转换数量。
- 优化简单的字符串:使用较少的状态(abcade应该给出两个状态,用于abc和ade)。[这真的有意义吗？]
- 优化没有替代的组。

- 优化只有一个__regex_action_free:n 的状态。
- 通过直接在状态 2 中插入__regex_action_success: 来优化其使用，而不是有额外的转换。
- 通过插入\int_step_... 函数的使用来优化。
- 组在 csnames 的正则表达式中不捕获；优化并记录。
- 更好的锚定、属性和类别码测试的“show”。
- \K是否真的需要一个新的状态?
- 在编译时，使用布尔变量 in_cs 和较少的魔术数字。
- 与其使用字符代码检查字符是否为特殊字符或字母数字，不如在正则表达式中使用\cs_if_exist 测试检查它是否为特殊字符。

以下功能可能在将来的某个时候实现。

- 一般的先行/后行断言。
- 在外部文件上进行正则表达式匹配。
- 具有先行/后行条件的条件子模式：“如果之后是 [...]，则 [...]”。
- (*..) 和 (?..) 序列以设置一些选项。
- pdfTEX 的 UTF-8 模式。
- 换行约定尚未完成。特别是，应该有一个选项使 . 不匹配换行符。此外，\A 应该与 ^ 不同，而 \Z、\z 和 $ 应该不同。
- Unicode 属性：\p{..} 和 \P{..}；\X 应该匹配任何“扩展”的 Unicode 序列。这需要操作大量数据，可能使用树状盒子。

下面的 PCRE 或 Perl 的功能可能会或可能不会被实现。

- 使用 (?C...) 或其他语法的调用：一些内部代码更改使这成为可能，在替换代码中找到标记时停止正则表达式替换可能很有用；这引发了潜在的\regex_break: 问题，以及在正则表达式代码中从 \tl_map_break: 调用的良好处理问题。还提出了正则表达式机制内嵌套调用的问题，这是一个问题，因为\fontdimen是全局的。
- 条件子模式（不是先行或后行条件的）：这是非正则的，对吧?
- 命名子模式：TEX 程序员迄今为止无需命名宏参数。

下面的 PCRE 或 Perl 的功能肯定不会被实现。

- 反向引用：非正则特性，需要回溯，速度极慢。
- 递归：这是非正则特性。
- 原子分组、贪婪量词：这些工具主要用于修复灾难性回溯，在非回溯算法中是不必要的，并且难以实现。
- 子例程调用：这种语法糖难以包含在非回溯算法中，特别是因为相应的组应该被视为原子的。
- 回溯控制动词：与回溯密切相关。
- `\ddd`，匹配八进制代码为 `ddd` 的字符：我们已经有了 `\x{...}`，并且语法与我们可以用于反向引用（`\1`，`\2`，等）的语法相似，这使得产生有用的错误消息变得更加困难。
- `\cx`，类似于 TeX 的 `\^^x`。
- 注释：TeX 已经有了自己的注释系统。
- `\Q...\E` 转义：这需要逐字读取参数，不在此模块的范围内。
- 在 UTF-8 模式下的单字节 `\C`：XeTeX 和 LuaTeX 直接为我们提供字符，将其拆分为字节是棘手的，依赖编码，而且很可能并不实用。

9 l3regex implementation

```
⟨*package⟩
⟨@@=regex⟩
```

9.1 Plan of attack

Most regex engines use backtracking. This allows to provide very powerful features (back-references come to mind first), but it is costly, and raises the problem of catastrophic backtracking. Since TeX is not first and foremost a programming language, complicated code tends to run slowly, and we must use faster, albeit slightly more restrictive, techniques, coming from automata theory.

Given a regular expression of n characters, we do the following:

- (Compiling.) Analyse the regex, finding invalid input, and convert it to an internal representation.

- (Building.) Convert the compiled regex to a non-deterministic finite automaton (NFA) with $O(n)$ states which accepts precisely token lists matching that regex.
- (Matching.) Loop through the query token list one token (one "position") at a time, exploring in parallel every possible path ("active thread") through the NFA, considering active threads in an order determined by the quantifiers' greediness.

We use the following vocabulary in the code comments (and in variable names).

- *Group*: index of the capturing group, -1 for non-capturing groups.
- *Position*: each token in the query is labelled by an integer ⟨*position*⟩, with `min_pos` $-$ 1 ≤ ⟨*position*⟩ ≤ `max_pos`. The lowest and highest positions `min_pos` $-$ 1 and `max_pos` correspond to imaginary begin and end markers (with non-existent category code and character code). `max_pos` is only set quite late in the processing.
- *Query*: the token list to which we apply the regular expression.
- *State*: each state of the NFA is labelled by an integer ⟨*state*⟩ with `min_state` ≤ ⟨*state*⟩ < `max_state`.
- *Active thread*: state of the NFA that is reached when reading the query token list for the matching. Those threads are ordered according to the greediness of quantifiers.
- *Step*: used when matching, starts at 0, incremented every time a character is read, and is not reset when searching for repeated matches. The integer `\l__regex_step_int` is a unique id for all the steps of the matching algorithm.

We use l3intarray to manipulate arrays of integers. We also abuse TeX's `\toks` registers, by accessing them directly by number rather than tying them to control sequence using the `\newtoks` allocation functions. Specifically, these arrays and `\toks` are used as follows. When building, `\toks`⟨*state*⟩ holds the tests and actions to perform in the ⟨*state*⟩ of the NFA. When matching,

- `\g__regex_state_active_intarray` holds the last ⟨*step*⟩ in which each ⟨*state*⟩ was active.
- `\g__regex_thread_info_intarray` consists of blocks for each ⟨*thread*⟩ (with `min_thread` ≤ ⟨*thread*⟩ < `max_thread`). Each block has 1+2`\l__regex_capturing_group_in`

entries: the ⟨*state*⟩ in which the ⟨*thread*⟩ currently is, followed by the beginnings of all submatches, and then the ends of all submatches. The ⟨*threads*⟩ are ordered starting from the best to the least preferred.

- \g__regex_submatch_prev_intarray, \g__regex_submatch_begin_intarray and \g__regex_submatch_end_intarray hold, for each submatch (as would be extracted by \regex_extract_all:nnN), the place where the submatch started to be looked for and its two end-points. For historical reasons, the minimum index is twice max_state, and the used registers go up to \l__regex_submatch_int. They are organized in blocks of \l__regex_capturing_group_int entries, each block corresponding to one match with all its submatches stored in consecutive entries.

When actually building the result,

- \toks⟨*position*⟩ holds ⟨*tokens*⟩ which o- and e-expand to the ⟨*position*⟩-th token in the query.
- \g__regex_balance_intarray holds the balance of begin-group and end-group character tokens which appear before that point in the token list.

The code is structured as follows. Variables are introduced in the relevant section. First we present some generic helper functions. Then comes the code for compiling a regular expression, and for showing the result of the compilation. The building phase converts a compiled regex to NFA states, and the automaton is run by the code in the following section. The only remaining brick is parsing the replacement text and performing the replacement. We are then ready for all the user functions. Finally, messages, and a little bit of tracing code.

9.2 Helpers

__regex_int_eval:w

Access the primitive: performance is key here, so we do not use the slower route *via* \int_eval:n.

```
\cs_new_eq:NN \__regex_int_eval:w \tex_numexpr:D
```

(__regex_int_eval:w 定义结束。)

__regex_standard_escapechar:

Make the \escapechar into the standard backslash.

```
\cs_new_protected:Npn \__regex_standard_escapechar:
  { \int_set:Nn \tex_escapechar:D { `\\ } }
```

(__*regex*_*standard*_*escapechar*: 定义结束。)

__regex_toks_use:w

Unpack a \toks given its number.

```
\cs_new:Npn \__regex_toks_use:w { \tex_the:D \tex_toks:D }
```

(__*regex*_*toks*_*use:w* 定义结束。)

__regex_toks_clear:N
__regex_toks_set:Nn
__regex_toks_set:No

Empty a \toks or set it to a value, given its number.

```
\cs_new_protected:Npn \__regex_toks_clear:N #1
  { \__regex_toks_set:Nn #1 { } }
\cs_new_eq:NN \__regex_toks_set:Nn \tex_toks:D
\cs_new_protected:Npn \__regex_toks_set:No #1
  { \tex_toks:D #1 \exp_after:wN }
```

(__*regex*_*toks*_*clear:N* 和 __*regex*_*toks*_*set:Nn* 定义结束。)

__regex_toks_memcpy:NNn

Copy #3 \toks registers from #2 onwards to #1 onwards, like C's memcpy.

```
\cs_new_protected:Npn \__regex_toks_memcpy:NNn #1#2#3
  {
    \prg_replicate:nn {#3}
      {
        \tex_toks:D #1 = \tex_toks:D #2
        \int_incr:N #1
        \int_incr:N #2
      }
  }
```

(__*regex*_*toks*_*memcpy:NNn* 定义结束。)

__regex_toks_put_left:Ne
__regex_toks_put_right:Ne
__regex_toks_put_right:Nn

During the building phase we wish to add e-expanded material to \toks, either to the left or to the right. The expansion is done "by hand" for optimization (these operations are used quite a lot). The Nn version of __regex_toks_put_right:Ne is provided because it is more efficient than e-expanding with \exp_not:n.

```
\cs_new_protected:Npn \__regex_toks_put_left:Ne #1#2
  {
    \cs_set_nopar:Npe \__regex_tmp:w { #2 }
    \tex_toks:D #1 \exp_after:wN \exp_after:wN \exp_after:wN
      { \exp_after:wN \__regex_tmp:w \tex_the:D \tex_toks:D #1 }
  }
\cs_new_protected:Npn \__regex_toks_put_right:Ne #1#2
  {
    \cs_set_nopar:Npe \__regex_tmp:w {#2}
    \tex_toks:D #1 \exp_after:wN
```

```
      { \tex_the:D \tex_toks:D \exp_after:wN #1 \__regex_tmp:w }
  }
\cs_new_protected:Npn \__regex_toks_put_right:Nn #1#2
  { \tex_toks:D #1 \exp_after:wN { \tex_the:D \tex_toks:D #1 #2 } }
```

(*__regex_toks_put_left:Ne* 和 *__regex_toks_put_right:Ne* 定义结束。)

__regex_curr_cs_to_str: Expands to the string representation of the token (known to be a control sequence) at the current position `\l__regex_curr_pos_int`. It should only be used in `e`/`x`-expansion to avoid losing a leading space.

```
\cs_new:Npn \__regex_curr_cs_to_str:
  {
    \exp_after:wN \exp_after:wN \exp_after:wN \cs_to_str:N
    \l__regex_curr_token_tl
  }
```

(*__regex_curr_cs_to_str:* 定义结束。)

__regex_intarray_item:NnF
__regex_intarray_item_aux:nNF

Item of intarray, with a default value.

```
\cs_new:Npn \__regex_intarray_item:NnF #1#2
  { \exp_args:Nf \__regex_intarray_item_aux:nNF { \int_eval:n {#2} } #1 }
\cs_new:Npn \__regex_intarray_item_aux:nNF #1#2
  {
    \if_int_compare:w #1 > \c_zero_int
      \exp_after:wN \use_i:nn
    \else:
      \exp_after:wN \use_ii:nn
    \fi:
    { \__kernel_intarray_item:Nn #2 {#1} }
  }
```

(*__regex_intarray_item:NnF* 和 *__regex_intarray_item_aux:nNF* 定义结束。)

__regex_maplike_break: Analogous to `\tl_map_break:`, this correctly exits `\tl_map_inline:nn` and similar constructions and jumps to the matching `\prg_break_point:Nn \__regex_maplike_break: { }`.

```
\cs_new:Npn \__regex_maplike_break:
  { \prg_map_break:Nn \__regex_maplike_break: { } }
```

(*__regex_maplike_break:* 定义结束。)

__regex_tl_odd_items:n
__regex_tl_even_items:n
__regex_tl_even_items_loop:nn

Map through a token list one pair at a time, leaving the odd-numbered or even-numbered items (the first item is numbered 1).

```
\cs_new:Npn \__regex_tl_odd_items:n #1 { \__regex_tl_even_items:n { ? #1 } }
\cs_new:Npn \__regex_tl_even_items:n #1
  {
    \__regex_tl_even_items_loop:nn #1 \q__regex_nil \q__regex_nil
    \prg_break_point:
  }
\cs_new:Npn \__regex_tl_even_items_loop:nn #1#2
  {
    \__regex_use_none_delimit_by_q_nil:w #2 \prg_break: \q__regex_nil
    { \exp_not:n {#2} }
    \__regex_tl_even_items_loop:nn
  }
```

(*__regex_tl_odd_items:n*, *__regex_tl_even_items:n*, 和 *__regex_tl_even_items_loop:nn* 定义结束。)

9.2.1 Constants and variables

__regex_tmp:w

Temporary function used for various short-term purposes.

```
\cs_new:Npn \__regex_tmp:w { }
```

(*__regex_tmp:w* 定义结束。)

\l__regex_internal_a_tl
\l__regex_internal_b_tl
\l__regex_internal_a_int
\l__regex_internal_b_int
\l__regex_internal_c_int
\l__regex_internal_bool
\l__regex_internal_seq
\g__regex_internal_tl

Temporary variables used for various purposes.

```
\tl_new:N   \l__regex_internal_a_tl
\tl_new:N   \l__regex_internal_b_tl
\int_new:N  \l__regex_internal_a_int
\int_new:N  \l__regex_internal_b_int
\int_new:N  \l__regex_internal_c_int
\bool_new:N \l__regex_internal_bool
\seq_new:N  \l__regex_internal_seq
\tl_new:N   \g__regex_internal_tl
```

(*\l__regex_internal_a_tl* 以及其它的定义结束。)

\l__regex_build_tl

This temporary variable is specifically for use with the `tl_build` machinery.

```
\tl_new:N \l__regex_build_tl
```

(*\l__regex_build_tl* 定义结束。)

\c__regex_no_match_regex

This regular expression matches nothing, but is still a valid regular expression. We could use a failing assertion, but I went for an empty class. It is used as the initial value for regular expressions declared using \regex_new:N.

```
\tl_const:Nn \c__regex_no_match_regex
  {
    \__regex_branch:n
      { \__regex_class:NnnnN \c_true_bool { } { 1 } { 0 } \c_true_bool }
  }
```

（*\c__regex_no_match_regex* 定义结束。）

\l__regex_balance_int

During this phase, \l__regex_balance_int counts the balance of begin-group and end-group character tokens which appear before a given point in the token list. This variable is also used to keep track of the balance in the replacement text.

```
\int_new:N \l__regex_balance_int
```

（*\l__regex_balance_int* 定义结束。）

9.2.2 Testing characters

\c__regex_ascii_min_int
\c__regex_ascii_max_control_int
\c__regex_ascii_max_int

```
\int_const:Nn \c__regex_ascii_min_int { 0 }
\int_const:Nn \c__regex_ascii_max_control_int { 31 }
\int_const:Nn \c__regex_ascii_max_int { 127 }
```

（*\c__regex_ascii_min_int*，*\c__regex_ascii_max_control_int*，和 *\c__regex_ascii_max_int* 定义结束。）

\c__regex_ascii_lower_int

```
\int_const:Nn \c__regex_ascii_lower_int { `a - `A }
```

（*\c__regex_ascii_lower_int* 定义结束。）

9.2.3 Internal auxiliaries

\q__regex_recursion_stop

Internal recursion quarks.

```
\quark_new:N \q__regex_recursion_stop
```

（*\q__regex_recursion_stop* 定义结束。）

\q__regex_nil

Internal quarks.

```
\quark_new:N \q__regex_nil
```

（*\q__regex_nil* 定义结束。）

egex_use_none_delimit_by_q_recursion_stop:w
_regex_use_i_delimit_by_q_recursion_stop:nw
__regex_use_none_delimit_by_q_nil:w

Functions to gobble up to a quark.

```
\cs_new:Npn \__regex_use_none_delimit_by_q_recursion_stop:w
  #1 \q__regex_recursion_stop { }
\cs_new:Npn \__regex_use_i_delimit_by_q_recursion_stop:nw
  #1 #2 \q__regex_recursion_stop {#1}
\cs_new:Npn \__regex_use_none_delimit_by_q_nil:w #1 \q__regex_nil { }
```

(*__regex_use_none_delimit_by_q_recursion_stop:w*, *__regex_use_i_delimit_by_q_recursion_stop:nw*, 和 *__regex_use_none_delimit_by_q_nil:w* 定义结束。)

__regex_quark_if_nil_p:n
__regex_quark_if_nil:n*TF*

Branching quark conditional.

```
\__kernel_quark_new_conditional:Nn \__regex_quark_if_nil:N { F }
```

(*__regex_quark_if_nil:nTF* 定义结束。)

__regex_break_point:TF
__regex_break_true:w

When testing whether a character of the query token list matches a given character class in the regular expression, we often have to test it against several ranges of characters, checking if any one of those matches. This is done with a structure like

```
⟨test1⟩ ... ⟨testn⟩
\__regex_break_point:TF {⟨true code⟩} {⟨false code⟩}
```

If any of the tests succeeds, it calls `\__regex_break_true:w`, which cleans up and leaves ⟨*true code*⟩ in the input stream. Otherwise, `\__regex_break_point:TF` leaves the ⟨*false code*⟩ in the input stream.

```
\cs_new_protected:Npn \__regex_break_true:w
  #1 \__regex_break_point:TF #2 #3 {#2}
\cs_new_protected:Npn \__regex_break_point:TF #1 #2 { #2 }
```

(*__regex_break_point:TF* 和 *__regex_break_true:w* 定义结束。)

__regex_item_reverse:n

This function makes showing regular expressions easier, and lets us define `\D` in terms of `\d` for instance. There is a subtlety: the end of the query is marked by -2, and thus matches `\D` and other negated properties; this case is caught by another part of the code.

```
\cs_new_protected:Npn \__regex_item_reverse:n #1
  {
    #1
    \__regex_break_point:TF { } \__regex_break_true:w
  }
```

(*__regex_item_reverse:n* 定义结束。)

__regex_item_caseful_equal:n
__regex_item_caseful_range:nn

Simple comparisons triggering `\__regex_break_true:w` when true.

```
\cs_new_protected:Npn \__regex_item_caseful_equal:n #1
  {
    \if_int_compare:w #1 = \l__regex_curr_char_int
      \exp_after:wN \__regex_break_true:w
    \fi:
  }
\cs_new_protected:Npn \__regex_item_caseful_range:nn #1 #2
  {
    \reverse_if:N \if_int_compare:w #1 > \l__regex_curr_char_int
      \reverse_if:N \if_int_compare:w #2 < \l__regex_curr_char_int
        \exp_after:wN \exp_after:wN \exp_after:wN \__regex_break_true:w
      \fi:
    \fi:
  }
```

(__regex_item_caseful_equal:n 和 __regex_item_caseful_range:nn 定义结束。)

__regex_item_caseless_equal:n
__regex_item_caseless_range:nn

For caseless matching, we perform the test both on the `curr_char` and on the `case_changed_char`. Before doing the second set of tests, we make sure that `case_changed_char` has been computed.

```
\cs_new_protected:Npn \__regex_item_caseless_equal:n #1
  {
    \if_int_compare:w #1 = \l__regex_curr_char_int
      \exp_after:wN \__regex_break_true:w
    \fi:
    \__regex_maybe_compute_ccc:
    \if_int_compare:w #1 = \l__regex_case_changed_char_int
      \exp_after:wN \__regex_break_true:w
    \fi:
  }
\cs_new_protected:Npn \__regex_item_caseless_range:nn #1 #2
  {
    \reverse_if:N \if_int_compare:w #1 > \l__regex_curr_char_int
      \reverse_if:N \if_int_compare:w #2 < \l__regex_curr_char_int
        \exp_after:wN \exp_after:wN \exp_after:wN \__regex_break_true:w
      \fi:
    \fi:
    \__regex_maybe_compute_ccc:
    \reverse_if:N \if_int_compare:w #1 > \l__regex_case_changed_char_int
      \reverse_if:N \if_int_compare:w #2 < \l__regex_case_changed_char_int
        \exp_after:wN \exp_after:wN \exp_after:wN \__regex_break_true:w
      \fi:
    \fi:
  }
```

(*__regex_item_caseless_equal:n* 和 *__regex_item_caseless_range:nn* 定义结束。)

__regex_compute_case_changed_char:

This function is called when `\l__regex_case_changed_char_int` has not yet been computed. If the current character code is in the range $[65, 90]$ (upper-case), then add 32, making it lowercase. If it is in the lower-case letter range $[97, 122]$, subtract 32.

```
\cs_new_protected:Npn \__regex_compute_case_changed_char:
  {
    \int_set_eq:NN \l__regex_case_changed_char_int \l__regex_curr_char_int
    \if_int_compare:w \l__regex_curr_char_int > `Z \exp_stop_f:
      \if_int_compare:w \l__regex_curr_char_int > `z \exp_stop_f: \else:
        \if_int_compare:w \l__regex_curr_char_int < `a \exp_stop_f: \else:
          \int_sub:Nn \l__regex_case_changed_char_int
            { \c__regex_ascii_lower_int }
        \fi:
      \fi:
    \else:
      \if_int_compare:w \l__regex_curr_char_int < `A \exp_stop_f: \else:
        \int_add:Nn \l__regex_case_changed_char_int
          { \c__regex_ascii_lower_int }
      \fi:
    \fi:
    \cs_set_eq:NN \__regex_maybe_compute_ccc: \prg_do_nothing:
  }
\cs_new_eq:NN \__regex_maybe_compute_ccc: \__regex_compute_case_changed_char:
```

(*__regex_compute_case_changed_char:* 定义结束。)

__regex_item_equal:n
__regex_item_range:nn

Those must always be defined to expand to a `caseful` (default) or `caseless` version, and not be protected: they must expand when compiling, to hard-code which tests are caseless or caseful.

```
\cs_new_eq:NN \__regex_item_equal:n ?
\cs_new_eq:NN \__regex_item_range:nn ?
```

(*__regex_item_equal:n* 和 *__regex_item_range:nn* 定义结束。)

__regex_item_catcode:nT
__regex_item_catcode_reverse:nT
__regex_item_catcode:

The argument is a sum of powers of 4 with exponents given by the allowed category codes (between 0 and 13). Dividing by a given power of 4 gives an odd result if and only if that category code is allowed. If the catcode does not match, then skip the character code tests which follow.

```
\cs_new_protected:Npn \__regex_item_catcode:
  {
    "
    \if_case:w \l__regex_curr_catcode_int
         1       \or: 4       \or: 10      \or: 40
    \or: 100     \or:         \or: 1000    \or: 4000
    \or: 10000   \or:         \or: 100000  \or: 400000
    \or: 1000000 \or: 4000000 \else: 1*0
    \fi:
  }
\cs_new_protected:Npn \__regex_item_catcode:nT #1
  {
    \if_int_odd:w \int_eval:n { #1 / \__regex_item_catcode: } \exp_stop_f:
      \exp_after:wN \use:n
    \else:
      \exp_after:wN \use_none:n
    \fi:
  }
\cs_new_protected:Npn \__regex_item_catcode_reverse:nT #1#2
  { \__regex_item_catcode:nT {#1} { \__regex_item_reverse:n {#2} } }
```

(__*regex*_*item*_*catcode:nT*, __*regex*_*item*_*catcode*_*reverse:nT*, 和 __*regex*_*item*_*catcode:* 定义结束。)

__regex_item_exact:nn
__regex_item_exact_cs:n

This matches an exact ⟨*category*⟩-⟨*character code*⟩ pair, or an exact control sequence, more precisely one of several possible control sequences, separated by \scan_stop:.

```
\cs_new_protected:Npn \__regex_item_exact:nn #1#2
  {
    \if_int_compare:w #1 = \l__regex_curr_catcode_int
      \if_int_compare:w #2 = \l__regex_curr_char_int
        \exp_after:wN \exp_after:wN \exp_after:wN \__regex_break_true:w
      \fi:
    \fi:
  }
\cs_new_protected:Npn \__regex_item_exact_cs:n #1
  {
    \int_compare:nNnTF \l__regex_curr_catcode_int = 0
      {
        \__kernel_tl_set:Ne \l__regex_internal_a_tl
          { \scan_stop: \__regex_curr_cs_to_str: \scan_stop: }
        \tl_if_in:noTF { \scan_stop: #1 \scan_stop: }
```

```
          \l__regex_internal_a_tl
          { \__regex_break_true:w } { }
      }
      { }
  }
```

(__*regex_item_exact:nn* 和 __*regex_item_exact_cs:n* 定义结束。)

__regex_item_cs:n

Match a control sequence (the argument is a compiled regex). First test the catcode of the current token to be zero. Then perform the matching test, and break if the csname indeed matches.

```
\cs_new_protected:Npn \__regex_item_cs:n #1
  {
    \int_compare:nNnT \l__regex_curr_catcode_int = 0
      {
        \group_begin:
          \__regex_single_match:
          \__regex_disable_submatches:
          \__regex_build_for_cs:n {#1}
          \bool_set_eq:NN \l__regex_saved_success_bool
            \g__regex_success_bool
          \exp_args:Ne \__regex_match_cs:n { \__regex_curr_cs_to_str: }
          \if_meaning:w \c_true_bool \g__regex_success_bool
            \group_insert_after:N \__regex_break_true:w
          \fi:
          \bool_gset_eq:NN \g__regex_success_bool
            \l__regex_saved_success_bool
        \group_end:
      }
  }
```

(__*regex_item_cs:n* 定义结束。)

9.2.4 Character property tests

__regex_prop_d:
__regex_prop_h:
__regex_prop_s:
__regex_prop_v:
__regex_prop_w:
__regex_prop_N:

Character property tests for `\d`, `\W`, *etc.* These character properties are not affected by the `(?i)` option. The characters recognized by each one are as follows: `\d=[0-9]`, `\w=[0-9A-Z_a-z]`, `\s=[\␣\^^I\^^J\^^L\^^M]`, `\h=[\␣\^^I]`, `\v=[\^^J-\^^M]`, and the upper case counterparts match anything that the lower case does not match. The order in which the various tests appear is optimized for usual mostly lower case letter text.

```
\cs_new_protected:Npn \__regex_prop_d:
  { \__regex_item_caseful_range:nn { `0 } { `9 } }
\cs_new_protected:Npn \__regex_prop_h:
  {
    \__regex_item_caseful_equal:n { `\ }
    \__regex_item_caseful_equal:n { `\^^I }
  }
\cs_new_protected:Npn \__regex_prop_s:
  {
    \__regex_item_caseful_equal:n { `\ }
    \__regex_item_caseful_equal:n { `\^^I }
    \__regex_item_caseful_equal:n { `\^^J }
    \__regex_item_caseful_equal:n { `\^^L }
    \__regex_item_caseful_equal:n { `\^^M }
  }
\cs_new_protected:Npn \__regex_prop_v:
  { \__regex_item_caseful_range:nn { `\^^J } { `\^^M } } % lf, vtab, ff, cr
\cs_new_protected:Npn \__regex_prop_w:
  {
    \__regex_item_caseful_range:nn { `a } { `z }
    \__regex_item_caseful_range:nn { `A } { `Z }
    \__regex_item_caseful_range:nn { `0 } { `9 }
    \__regex_item_caseful_equal:n { `_ }
  }
\cs_new_protected:Npn \__regex_prop_N:
  {
    \__regex_item_reverse:n
      { \__regex_item_caseful_equal:n { `\^^J } }
  }
```

(__*regex_prop_d:* 以及其它的定义结束。)

__regex_posix_alnum:
__regex_posix_alpha:
__regex_posix_ascii:
__regex_posix_blank:
__regex_posix_cntrl:
__regex_posix_digit:
__regex_posix_graph:
__regex_posix_lower:
__regex_posix_print:
__regex_posix_punct:
__regex_posix_space:
__regex_posix_upper:
__regex_posix_word:
__regex_posix_xdigit:

POSIX properties. No surprise.

```
\cs_new_protected:Npn \__regex_posix_alnum:
  { \__regex_posix_alpha: \__regex_posix_digit: }
\cs_new_protected:Npn \__regex_posix_alpha:
  { \__regex_posix_lower: \__regex_posix_upper: }
\cs_new_protected:Npn \__regex_posix_ascii:
  {
    \__regex_item_caseful_range:nn
      \c__regex_ascii_min_int
      \c__regex_ascii_max_int
  }
\cs_new_eq:NN \__regex_posix_blank: \__regex_prop_h:
```

```
\cs_new_protected:Npn \__regex_posix_cntrl:
  {
    \__regex_item_caseful_range:nn
      \c__regex_ascii_min_int
      \c__regex_ascii_max_control_int
    \__regex_item_caseful_equal:n \c__regex_ascii_max_int
  }
\cs_new_eq:NN \__regex_posix_digit: \__regex_prop_d:
\cs_new_protected:Npn \__regex_posix_graph:
  { \__regex_item_caseful_range:nn { `! } { `\~ } }
\cs_new_protected:Npn \__regex_posix_lower:
  { \__regex_item_caseful_range:nn { `a } { `z } }
\cs_new_protected:Npn \__regex_posix_print:
  { \__regex_item_caseful_range:nn { `\  } { `\~ } }
\cs_new_protected:Npn \__regex_posix_punct:
  {
    \__regex_item_caseful_range:nn { `! } { `/ }
    \__regex_item_caseful_range:nn { `: } { `@ }
    \__regex_item_caseful_range:nn { `[ } { `` }
    \__regex_item_caseful_range:nn { `\{ } { `\~ }
  }
\cs_new_protected:Npn \__regex_posix_space:
  {
    \__regex_item_caseful_equal:n { `\  }
    \__regex_item_caseful_range:nn { `\^^I } { `\^^M }
  }
\cs_new_protected:Npn \__regex_posix_upper:
  { \__regex_item_caseful_range:nn { `A } { `Z } }
\cs_new_eq:NN \__regex_posix_word: \__regex_prop_w:
\cs_new_protected:Npn \__regex_posix_xdigit:
  {
    \__regex_posix_digit:
    \__regex_item_caseful_range:nn { `A } { `F }
    \__regex_item_caseful_range:nn { `a } { `f }
  }
```

(*__regex_posix_alnum: 以及其它的定义结束。*)

9.2.5 Simple character escape

Before actually parsing the regular expression or the replacement text, we go through them once, converting `\n` to the character 10, *etc.* In this pass, we also convert any special character (`*`, `?`, `{`, etc.) or escaped alphanumeric character into a marker indicating that this was a special sequence, and replace escaped special characters and non-escaped alphanumeric characters by markers indicating that those were “raw” characters. The rest of the code can then avoid caring about escaping issues (those can become quite complex to handle in combination with ranges in character classes).

Usage: `\__regex_escape_use:nnnn` ⟨*inline 1*⟩ ⟨*inline 2*⟩ ⟨*inline 3*⟩ {⟨*token list*⟩} The ⟨*token list*⟩ is converted to a string, then read from left to right, interpreting backslashes as escaping the next character. Unescaped characters are fed to the function ⟨*inline 1*⟩, and escaped characters are fed to the function ⟨*inline 2*⟩ within an `e`-expansion context (typically those functions perform some tests on their argument to decide how to output them). The escape sequences `\a`, `\e`, `\f`, `\n`, `\r`, `\t` and `\x` are recognized, and those are replaced by the corresponding character, then fed to ⟨*inline 3*⟩. The result is then left in the input stream. Spaces are ignored unless escaped.

The conversion is done within an `e`-expanding assignment.

`\__regex_escape_use:nnnn` The result is built in `\l__regex_internal_a_tl`, which is then left in the input stream. Tracing code is added as appropriate inside this token list. Go through `#4` once, applying `#1`, `#2`, or `#3` as relevant to each character (after de-escaping it).

```
\cs_new_protected:Npn \__regex_escape_use:nnnn #1#2#3#4
  {
    \group_begin:
      \tl_clear:N \l__regex_internal_a_tl
      \cs_set:Npn \__regex_escape_unescaped:N ##1 { #1 }
      \cs_set:Npn \__regex_escape_escaped:N ##1 { #2 }
      \cs_set:Npn \__regex_escape_raw:N ##1 { #3 }
      \__regex_standard_escapechar:
      \__kernel_tl_gset:Ne \g__regex_internal_tl
        { \__kernel_str_to_other_fast:n {#4} }
      \tl_put_right:Ne \l__regex_internal_a_tl
        {
          \exp_after:wN \__regex_escape_loop:N \g__regex_internal_tl
          \scan_stop: \prg_break_point:
        }
      \exp_after:wN
    \group_end:
    \l__regex_internal_a_tl
  }
```

(*__regex_escape_use:nnnn* 定义结束。)

__regex_escape_loop:N
__regex_escape_\:w

__regex_escape_loop:N reads one character: if it is special (space, backslash, or end-marker), perform the associated action, otherwise it is simply an unescaped character. After a backslash, the same is done, but unknown characters are "escaped".

```
\cs_new:Npn \__regex_escape_loop:N #1
  {
    \cs_if_exist_use:cF { __regex_escape_\token_to_str:N #1:w }
      { \__regex_escape_unescaped:N #1 }
    \__regex_escape_loop:N
  }
\cs_new:cpn { __regex_escape_ \c_backslash_str :w }
    \__regex_escape_loop:N #1
  {
    \cs_if_exist_use:cF { __regex_escape_/\token_to_str:N #1:w }
      { \__regex_escape_escaped:N #1 }
    \__regex_escape_loop:N
  }
```

(*__regex_escape_loop:N* 和 *__regex_escape_\:w* 定义结束。)

__regex_escape_unescaped:N
__regex_escape_escaped:N
__regex_escape_raw:N

Those functions are never called before being given a new meaning, so their definitions here don't matter.

```
\cs_new_eq:NN \__regex_escape_unescaped:N ?
\cs_new_eq:NN \__regex_escape_escaped:N   ?
\cs_new_eq:NN \__regex_escape_raw:N       ?
```

(*__regex_escape_unescaped:N*, *__regex_escape_escaped:N*, 和 *__regex_escape_raw:N* 定义结束。)

__regex_escape_\scan_stop::w
__regex_escape_/\scan_stop::w
__regex_escape_/a:w
__regex_escape_/e:w
__regex_escape_/f:w
__regex_escape_/n:w
__regex_escape_/r:w
__regex_escape_/t:w
__regex_escape_ :w

The loop is ended upon seeing the end-marker "break", with an error if the string ended in a backslash. Spaces are ignored, and \a, \e, \f, \n, \r, \t take their meaning here.

```
\cs_new_eq:cN { __regex_escape_ \iow_char:N\\scan_stop: :w } \prg_break:
\cs_new:cpn { __regex_escape_/ \iow_char:N\\scan_stop: :w }
  {
    \msg_expandable_error:nn { regex } { trailing-backslash }
    \prg_break:
  }
\cs_new:cpn { __regex_escape_~:w } { }
\cs_new:cpe { __regex_escape_/a:w }
  { \exp_not:N \__regex_escape_raw:N \iow_char:N \^^G }
\cs_new:cpe { __regex_escape_/t:w }
  { \exp_not:N \__regex_escape_raw:N \iow_char:N \^^I }
\cs_new:cpe { __regex_escape_/n:w }
```

```
  { \exp_not:N \__regex_escape_raw:N \iow_char:N \^^J }
\cs_new:cpe { __regex_escape_/f:w }
  { \exp_not:N \__regex_escape_raw:N \iow_char:N \^^L }
\cs_new:cpe { __regex_escape_/r:w }
  { \exp_not:N \__regex_escape_raw:N \iow_char:N \^^M }
\cs_new:cpe { __regex_escape_/e:w }
  { \exp_not:N \__regex_escape_raw:N \iow_char:N \^^[ }
```

(*__regex_escape_\scan_stop::w* 以及其它的定义结束。)

__regex_escape_/x:w
__regex_escape_x_end:w
__regex_escape_x_large:n

When \x is encountered, __regex_escape_x_test:N is responsible for grabbing some hexadecimal digits, and feeding the result to __regex_escape_x_end:w. If the number is too big interrupt the assignment and produce an error, otherwise call __regex_escape_raw:N on the corresponding character token.

```
\cs_new:cpn { __regex_escape_/x:w } \__regex_escape_loop:N
  {
    \exp_after:wN \__regex_escape_x_end:w
    \int_value:w "0 \__regex_escape_x_test:N
  }
\cs_new:Npn \__regex_escape_x_end:w #1 ;
  {
    \int_compare:nNnTF {#1} > \c_max_char_int
      {
        \msg_expandable_error:nnff { regex } { x-overflow }
          {#1} { \int_to_Hex:n {#1} }
      }
      {
        \exp_last_unbraced:Nf \__regex_escape_raw:N
          { \char_generate:nn {#1} { 12 } }
      }
  }
```

(*__regex_escape_/x:w*, *__regex_escape_x_end:w*, 和 *__regex_escape_x_large:n* 定义结束。)

__regex_escape_x_test:N
__regex_escape_x_testii:N

Find out whether the first character is a left brace (allowing any number of hexadecimal digits), or not (allowing up to two hexadecimal digits). We need to check for the end-of-string marker. Eventually, call either __regex_escape_x_loop:N or __regex_escape_x:N.

```
\cs_new:Npn \__regex_escape_x_test:N #1
  {
    \if_meaning:w \scan_stop: #1
      \exp_after:wN \use_i:nnn \exp_after:wN ;
    \fi:
    \use:n
      {
        \if_charcode:w \c_space_token #1
          \exp_after:wN \__regex_escape_x_test:N
        \else:
          \exp_after:wN \__regex_escape_x_testii:N
          \exp_after:wN #1
        \fi:
      }
  }
\cs_new:Npn \__regex_escape_x_testii:N #1
  {
    \if_charcode:w \c_left_brace_str #1
      \exp_after:wN \__regex_escape_x_loop:N
    \else:
      \__regex_hexadecimal_use:NTF #1
        { \exp_after:wN \__regex_escape_x:N }
        { ; \exp_after:wN \__regex_escape_loop:N \exp_after:wN #1 }
    \fi:
  }
```

(__regex_escape_x_test:N 和 __regex_escape_x_testii:N 定义结束。)

__regex_escape_x:N

This looks for the second digit in the unbraced case.

```
\cs_new:Npn \__regex_escape_x:N #1
  {
    \if_meaning:w \scan_stop: #1
      \exp_after:wN \use_i:nnn \exp_after:wN ;
    \fi:
    \use:n
      {
        \__regex_hexadecimal_use:NTF #1
          { ; \__regex_escape_loop:N }
          { ; \__regex_escape_loop:N #1 }
      }
  }
```

(__regex_escape_x:N 定义结束。)

__regex_escape_x_loop:N
__regex_escape_x_loop_error:

Grab hexadecimal digits, skip spaces, and at the end, check that there is a right brace, otherwise raise an error outside the assignment.

```
\cs_new:Npn \__regex_escape_x_loop:N #1
```

```
  {
    \if_meaning:w \scan_stop: #1
      \exp_after:wN \use_ii:nnn
    \fi:
    \use_ii:nn
      { ; \__regex_escape_x_loop_error:n { } {#1} }
      {
        \__regex_hexadecimal_use:NTF #1
          { \__regex_escape_x_loop:N }
          {
            \token_if_eq_charcode:NNTF \c_space_token #1
              { \__regex_escape_x_loop:N }
              {
                ;
                \exp_after:wN
                \token_if_eq_charcode:NNTF \c_right_brace_str #1
                  { \__regex_escape_loop:N }
                  { \__regex_escape_x_loop_error:n {#1} }
              }
          }
      }
  }
\cs_new:Npn \__regex_escape_x_loop_error:n #1
  {
    \msg_expandable_error:nnn { regex } { x-missing-rbrace } {#1}
    \__regex_escape_loop:N #1
  }
```

(__*regex*_*escape*_*x*_*loop:N* 和 __*regex*_*escape*_*x*_*loop*_*error:* 定义结束。)

__regex_hexadecimal_use:NTF TeX detects uppercase hexadecimal digits for us but not the lowercase letters, which we need to detect and replace by their uppercase counterpart.

```
\prg_new_conditional:Npnn \__regex_hexadecimal_use:N #1 { TF }
  {
    \if_int_compare:w 1 < "1 \token_to_str:N #1 \exp_stop_f:
      #1 \prg_return_true:
    \else:
      \if_case:w
        \int_eval:n { \exp_after:wN ` \token_to_str:N #1 - `a }
           A
      \or: B
      \or: C
      \or: D
      \or: E
      \or: F
      \else:
        \prg_return_false:
        \exp_after:wN \use_none:n
      \fi:
      \prg_return_true:
    \fi:
  }
```

(*__regex_hexadecimal_use:NTF* 定义结束。)

__regex_char_if_alphanumeric:NTF
__regex_char_if_special:NTF

These two tests are used in the first pass when parsing a regular expression. That pass is responsible for finding escaped and non-escaped characters, and recognizing which ones have special meanings and which should be interpreted as "raw" characters. Namely,

- alphanumerics are "raw" if they are not escaped, and may have a special meaning when escaped;
- non-alphanumeric printable ascii characters are "raw" if they are escaped, and may have a special meaning when not escaped;
- characters other than printable ascii are always "raw".

The code is ugly, and highly based on magic numbers and the ascii codes of characters. This is mostly unavoidable for performance reasons. Maybe the tests can be optimized a little bit more. Here, "alphanumeric" means `0`–`9`, `A`–`Z`, `a`–`z`; "special" character means non-alphanumeric but printable ascii, from space (hex `20`) to `del` (hex `7E`).

```
\prg_new_conditional:Npnn \__regex_char_if_special:N #1 { TF }
  {
    \if_int_compare:w `#1 > `Z \exp_stop_f:
      \if_int_compare:w `#1 > `z \exp_stop_f:
        \if_int_compare:w `#1 < \c__regex_ascii_max_int
          \prg_return_true: \else: \prg_return_false: \fi:
      \else:
        \if_int_compare:w `#1 < `a \exp_stop_f:
          \prg_return_true: \else: \prg_return_false: \fi:
      \fi:
    \else:
      \if_int_compare:w `#1 > `9 \exp_stop_f:
        \if_int_compare:w `#1 < `A \exp_stop_f:
          \prg_return_true: \else: \prg_return_false: \fi:
      \else:
        \if_int_compare:w `#1 < `0 \exp_stop_f:
          \if_int_compare:w `#1 < `\ \exp_stop_f:
            \prg_return_false: \else: \prg_return_true: \fi:
        \else: \prg_return_false: \fi:
      \fi:
    \fi:
  }
\prg_new_conditional:Npnn \__regex_char_if_alphanumeric:N #1 { TF }
  {
    \if_int_compare:w `#1 > `Z \exp_stop_f:
      \if_int_compare:w `#1 > `z \exp_stop_f:
        \prg_return_false:
      \else:
        \if_int_compare:w `#1 < `a \exp_stop_f:
          \prg_return_false: \else: \prg_return_true: \fi:
      \fi:
    \else:
      \if_int_compare:w `#1 > `9 \exp_stop_f:
        \if_int_compare:w `#1 < `A \exp_stop_f:
          \prg_return_false: \else: \prg_return_true: \fi:
      \else:
        \if_int_compare:w `#1 < `0 \exp_stop_f:
          \prg_return_false: \else: \prg_return_true: \fi:
      \fi:
    \fi:
  }
```

(*__regex_char_if_alphanumeric:NTF* 和 *__regex_char_if_special:NTF* 定义结束。)

9.3 Compiling

A regular expression starts its life as a string of characters. In this section, we convert it to internal instructions, resulting in a "compiled" regular expression. This compiled expression is then turned into states of an automaton in the building phase. Compiled regular expressions consist of the following:

- `\__regex_class:NnnnN` ⟨*boolean*⟩ `{`⟨*tests*⟩`}` `{`⟨*min*⟩`}` `{`⟨*more*⟩`}` ⟨*lazyness*⟩
- `\__regex_group:nnnN` `{`⟨*branches*⟩`}` `{`⟨*min*⟩`}` `{`⟨*more*⟩`}` ⟨*lazyness*⟩, also `\__regex_group_no_capture:nnnN` and `\__regex_group_resetting:nnnN` with the same

syntax.

- `\__regex_branch:n {`⟨*contents*⟩`}`
- `\__regex_command_K:`
- `\__regex_assertion:Nn` ⟨*boolean*⟩ `{`⟨*assertion test*⟩`}`, where the ⟨*assertion test*⟩ is `\__regex_b_test:` or `\__regex_Z_test:` or `\__regex_A_test:` or `\__regex_G_test:`

Tests can be the following:

- `\__regex_item_caseful_equal:n {`⟨*char code*⟩`}`
- `\__regex_item_caseless_equal:n {`⟨*char code*⟩`}`
- `\__regex_item_caseful_range:nn {`⟨*min*⟩`} {`⟨*max*⟩`}`
- `\__regex_item_caseless_range:nn {`⟨*min*⟩`} {`⟨*max*⟩`}`
- `\__regex_item_catcode:nT {`⟨*catcode bitmap*⟩`} {`⟨*tests*⟩`}`
- `\__regex_item_catcode_reverse:nT {`⟨*catcode bitmap*⟩`} {`⟨*tests*⟩`}`
- `\__regex_item_reverse:n {`⟨*tests*⟩`}`
- `\__regex_item_exact:nn {`⟨*catcode*⟩`} {`⟨*char code*⟩`}`
- `\__regex_item_exact_cs:n {`⟨*csnames*⟩`}`, more precisely given as ⟨*csname*⟩ `\scan_stop:` ⟨*csname*⟩ `\scan_stop:` ⟨*csname*⟩ and so on in a brace group.
- `\__regex_item_cs:n {`⟨*compiled regex*⟩`}`

9.3.1 Variables used when compiling

`\l__regex_group_level_int` We make sure to open the same number of groups as we close.

```
\int_new:N \l__regex_group_level_int
```

(*\l__regex_group_level_int* 定义结束。)

`\l__regex_mode_int`
`\c__regex_cs_in_class_mode_int`
`\c__regex_cs_mode_int`
`\c__regex_outer_mode_int`
`\c__regex_catcode_mode_int`
`\c__regex_class_mode_int`
`\c__regex_catcode_in_class_mode_int`

While compiling, ten modes are recognized, labelled −63, −23, −6, −2, 0, 2, 3, 6, 23, 63. See section 9.3.3. We only define some of these as constants.

```
\int_new:N \l__regex_mode_int
\int_const:Nn \c__regex_cs_in_class_mode_int { -6 }
\int_const:Nn \c__regex_cs_mode_int { -2 }
\int_const:Nn \c__regex_outer_mode_int { 0 }
```

```
\int_const:Nn \c__regex_catcode_mode_int { 2 }
\int_const:Nn \c__regex_class_mode_int { 3 }
\int_const:Nn \c__regex_catcode_in_class_mode_int { 6 }
```

(\l__regex_mode_int 以及其它的定义结束。)

\l__regex_catcodes_int
\l__regex_default_catcodes_int
\l__regex_catcodes_bool

We wish to allow constructions such as `\c[^BE](..\cL[a-z]..)`, where the outer catcode test applies to the whole group, but is superseded by the inner catcode test. For this to work, we need to keep track of lists of allowed category codes: `\l__regex_catcodes_int` and `\l__regex_default_catcodes_int` are bitmaps, sums of 4^c, for all allowed catcodes c. The latter is local to each capturing group, and we reset `\l__regex_catcodes_int` to that value after each character or class, changing it only when encountering a `\c` escape. The boolean records whether the list of categories of a catcode test has to be inverted: compare `\c[^BE]` and `\c[BE]`.

```
\int_new:N \l__regex_catcodes_int
\int_new:N \l__regex_default_catcodes_int
\bool_new:N \l__regex_catcodes_bool
```

(\l__regex_catcodes_int, \l__regex_default_catcodes_int, 和 \l__regex_catcodes_bool 定义结束。)

\c__regex_catcode_C_int
\c__regex_catcode_B_int
\c__regex_catcode_E_int
\c__regex_catcode_M_int
\c__regex_catcode_T_int
\c__regex_catcode_P_int
\c__regex_catcode_U_int
\c__regex_catcode_D_int
\c__regex_catcode_S_int
\c__regex_catcode_L_int
\c__regex_catcode_O_int
\c__regex_catcode_A_int
\c__regex_all_catcodes_int

Constants: 4^c for each category, and the sum of all powers of 4.

```
\int_const:Nn \c__regex_catcode_C_int { "1 }
\int_const:Nn \c__regex_catcode_B_int { "4 }
\int_const:Nn \c__regex_catcode_E_int { "10 }
\int_const:Nn \c__regex_catcode_M_int { "40 }
\int_const:Nn \c__regex_catcode_T_int { "100 }
\int_const:Nn \c__regex_catcode_P_int { "1000 }
\int_const:Nn \c__regex_catcode_U_int { "4000 }
\int_const:Nn \c__regex_catcode_D_int { "10000 }
\int_const:Nn \c__regex_catcode_S_int { "100000 }
\int_const:Nn \c__regex_catcode_L_int { "400000 }
\int_const:Nn \c__regex_catcode_O_int { "1000000 }
\int_const:Nn \c__regex_catcode_A_int { "4000000 }
\int_const:Nn \c__regex_all_catcodes_int { "5515155 }
```

(\c__regex_catcode_C_int 以及其它的定义结束。)

\l__regex_internal_regex

The compilation step stores its result in this variable.

```
\cs_new_eq:NN \l__regex_internal_regex \c__regex_no_match_regex
```

(\l__regex_internal_regex 定义结束。)

\l__regex_show_prefix_seq This sequence holds the prefix that makes up the line displayed to the user. The various items must be removed from the right, which is tricky with a token list, hence we use a sequence.

```
\seq_new:N \l__regex_show_prefix_seq
```

(*\l__regex_show_prefix_seq* 定义结束。)

\l__regex_show_lines_int A hack. To know whether a given class has a single item in it or not, we count the number of lines when showing the class.

```
\int_new:N \l__regex_show_lines_int
```

(*\l__regex_show_lines_int* 定义结束。)

9.3.2 Generic helpers used when compiling

__regex_two_if_eq:NNNNTF Used to compare pairs of things like `\__regex_compile_special:N ?` together. It's often inconvenient to get the catcodes of the character to match so we just compare the character code. Besides, the expanding behaviour of `\if:w` is very useful as that means we can use `\c_left_brace_str` and the like.

```
\prg_new_conditional:Npnn \__regex_two_if_eq:NNNN #1#2#3#4 { TF }
  {
    \if_meaning:w #1 #3
      \if:w #2 #4
        \prg_return_true:
      \else:
        \prg_return_false:
      \fi:
    \else:
      \prg_return_false:
    \fi:
  }
```

(*__regex_two_if_eq:NNNNTF* 定义结束。)

__regex_get_digits:NTFw
__regex_get_digits_loop:w
If followed by some raw digits, collect them one by one in the integer variable `#1`, and take the `true` branch. Otherwise, take the `false` branch.

```
\cs_new_protected:Npn \__regex_get_digits:NTFw #1#2#3#4#5
  {
    \__regex_if_raw_digit:NNTF #4 #5
      { #1 = #5 \__regex_get_digits_loop:nw {#2} }
      { #3 #4 #5 }
  }
```

```
\cs_new:Npn \__regex_get_digits_loop:nw #1#2#3
  {
    \__regex_if_raw_digit:NNTF #2 #3
      { #3 \__regex_get_digits_loop:nw {#1} }
      { \scan_stop: #1 #2 #3 }
  }
```

(*__regex_get_digits:NTFw* 和 *__regex_get_digits_loop:w* 定义结束。)

__regex_if_raw_digit:NNTF

Test used when grabbing digits for the {m,n} quantifier. It only accepts non-escaped digits.

```
\prg_new_conditional:Npnn \__regex_if_raw_digit:NN #1#2 { TF }
  {
    \if_meaning:w \__regex_compile_raw:N #1
      \if_int_compare:w 1 < 1 #2 \exp_stop_f:
        \prg_return_true:
      \else:
        \prg_return_false:
      \fi:
    \else:
      \prg_return_false:
    \fi:
  }
```

(*__regex_if_raw_digit:NNTF* 定义结束。)

9.3.3 Mode

When compiling the NFA corresponding to a given regex string, we can be in ten distinct modes, which we label by some magic numbers:

-6 [\c{...}] control sequence in a class,

-2 \c{...} control sequence,

0 ... outer,

2 \c... catcode test,

6 [\c...] catcode test in a class,

-63 [\c{[...]}] class inside mode −6,

-23 \c{[...]} class inside mode −2,

3 `[...]` class inside mode 0,

23 `\c[...]` class inside mode 2,

63 `[\c[...]]` class inside mode 6.

This list is exhaustive, because `\c` escape sequences cannot be nested, and character classes cannot be nested directly. The choice of numbers is such as to optimize the most useful tests, and make transitions from one mode to another as simple as possible.

- Even modes mean that we are not directly in a character class. In this case, a left bracket appends 3 to the mode. In a character class, a right bracket changes the mode as $m \to (m - 15)/13$, truncated.
- Grouping, assertion, and anchors are allowed in non-positive even modes (0, -2, -6), and do not change the mode. Otherwise, they trigger an error.
- A left bracket is special in even modes, appending 3 to the mode; in those modes, quantifiers and the dot are recognized, and the right bracket is normal. In odd modes (within classes), the left bracket is normal, but the right bracket ends the class, changing the mode from m to $(m - 15)/13$, truncated; also, ranges are recognized.
- In non-negative modes, left and right braces are normal. In negative modes, however, left braces trigger a warning; right braces end the control sequence, going from -2 to 0 or -6 to 3, with error recovery for odd modes.
- Properties (such as the `\d` character class) can appear in any mode.

`\__regex_if_in_class:TF` Test whether we are directly in a character class (at the innermost level of nesting). There, many escape sequences are not recognized, and special characters are normal. Also, for every raw character, we must look ahead for a possible raw dash.

```
\cs_new:Npn \__regex_if_in_class:TF
  {
    \if_int_odd:w \l__regex_mode_int
      \exp_after:wN \use_i:nn
    \else:
      \exp_after:wN \use_ii:nn
    \fi:
  }
```

(*__regex_if_in_class:TF* 定义结束。)

__regex_if_in_cs:TF

Right braces are special only directly inside control sequences (at the inner-most level of nesting, not counting groups).

```
\cs_new:Npn \__regex_if_in_cs:TF
  {
    \if_int_odd:w \l__regex_mode_int
      \exp_after:wN \use_ii:nn
    \else:
      \if_int_compare:w \l__regex_mode_int < \c__regex_outer_mode_int
        \exp_after:wN \exp_after:wN \exp_after:wN \use_i:nn
      \else:
        \exp_after:wN \exp_after:wN \exp_after:wN \use_ii:nn
      \fi:
    \fi:
  }
```

(__*regex*_*if*_*in*_*cs:TF* 定义结束。)

__regex_if_in_class_or_catcode:TF

Assertions are only allowed in modes 0, −2, and −6, *i.e.*, even, non-positive modes.

```
\cs_new:Npn \__regex_if_in_class_or_catcode:TF
  {
    \if_int_odd:w \l__regex_mode_int
      \exp_after:wN \use_i:nn
    \else:
      \if_int_compare:w \l__regex_mode_int > \c__regex_outer_mode_int
        \exp_after:wN \exp_after:wN \exp_after:wN \use_i:nn
      \else:
        \exp_after:wN \exp_after:wN \exp_after:wN \use_ii:nn
      \fi:
    \fi:
  }
```

(__*regex*_*if*_*in*_*class*_*or*_*catcode:TF* 定义结束。)

__regex_if_within_catcode:TF

This test takes the true branch if we are in a catcode test, either immediately following it (modes 2 and 6) or in a class on which it applies (modes 23 and 63). This is used to tweak how left brackets behave in modes 2 and 6.

```
\cs_new:Npn \__regex_if_within_catcode:TF
  {
    \if_int_compare:w \l__regex_mode_int > \c__regex_outer_mode_int
      \exp_after:wN \use_i:nn
    \else:
      \exp_after:wN \use_ii:nn
    \fi:
  }
```

(__*regex_if_within_catcode:TF* 定义结束。)

__regex_chk_c_allowed:T The `\c` escape sequence is only allowed in modes 0 and 3, *i.e.*, not within any other `\c` escape sequence.

```
\cs_new_protected:Npn \__regex_chk_c_allowed:T
  {
    \if_int_compare:w \l__regex_mode_int = \c__regex_outer_mode_int
      \exp_after:wN \use:n
    \else:
      \if_int_compare:w \l__regex_mode_int = \c__regex_class_mode_int
        \exp_after:wN \exp_after:wN \exp_after:wN \use:n
      \else:
        \msg_error:nn { regex } { c-bad-mode }
        \exp_after:wN \exp_after:wN \exp_after:wN \use_none:n
      \fi:
    \fi:
  }
```

(__*regex_chk_c_allowed:T* 定义结束。)

__regex_mode_quit_c: This function changes the mode as it is needed just after a catcode test.

```
\cs_new_protected:Npn \__regex_mode_quit_c:
  {
    \if_int_compare:w \l__regex_mode_int = \c__regex_catcode_mode_int
      \int_set_eq:NN \l__regex_mode_int \c__regex_outer_mode_int
    \else:
      \if_int_compare:w \l__regex_mode_int =
        \c__regex_catcode_in_class_mode_int
        \int_set_eq:NN \l__regex_mode_int \c__regex_class_mode_int
      \fi:
    \fi:
  }
```

(__*regex_mode_quit_c:* 定义结束。)

9.3.4 Framework

__regex_compile:w
__regex_compile_end: Used when compiling a user regex or a regex for the `\c{...}` escape sequence within another regex. Start building a token list within a group (with `e`-expansion at the outset), and set a few variables (group level, catcodes), then start the first branch.

At the end, make sure there are no dangling classes nor groups, close the last branch: we are done building `\l__regex_internal_regex`.

```
\cs_new_protected:Npn \__regex_compile:w
  {
    \group_begin:
      \tl_build_begin:N \l__regex_build_tl
      \int_zero:N \l__regex_group_level_int
      \int_set_eq:NN \l__regex_default_catcodes_int
        \c__regex_all_catcodes_int
      \int_set_eq:NN \l__regex_catcodes_int \l__regex_default_catcodes_int
      \cs_set:Npn \__regex_item_equal:n  { \__regex_item_caseful_equal:n }
      \cs_set:Npn \__regex_item_range:nn { \__regex_item_caseful_range:nn }
      \tl_build_put_right:Nn \l__regex_build_tl
        { \__regex_branch:n { \if_false: } \fi: }
  }
\cs_new_protected:Npn \__regex_compile_end:
  {
      \__regex_if_in_class:TF
        {
          \msg_error:nn { regex } { missing-rbrack }
          \use:c { __regex_compile_]: }
          \prg_do_nothing: \prg_do_nothing:
        }
        { }
      \if_int_compare:w \l__regex_group_level_int > \c_zero_int
        \msg_error:nne { regex } { missing-rparen }
          { \int_use:N \l__regex_group_level_int }
        \prg_replicate:nn
          { \l__regex_group_level_int }
          {
              \tl_build_put_right:Nn \l__regex_build_tl
                {
                  \if_false: { \fi: }
                  \if_false: { \fi: } { 1 } { 0 } \c_true_bool
                }
              \tl_build_end:N \l__regex_build_tl
              \exp_args:NNNo
            \group_end:
            \tl_build_put_right:Nn \l__regex_build_tl
              { \l__regex_build_tl }
          }
      \fi:
```

```
      \tl_build_put_right:Nn \l__regex_build_tl { \if_false: { \fi: } }
      \tl_build_end:N \l__regex_build_tl
      \exp_args:NNNe
    \group_end:
    \tl_set:Nn \l__regex_internal_regex { \l__regex_build_tl }
  }
```

(*__regex_compile:w* 和 *__regex_compile_end:* 定义结束。)

__regex_compile:n

The compilation is done between `\__regex_compile:w` and `\__regex_compile_end:`, starting in mode 0. Then `\__regex_escape_use:nnnn` distinguishes special characters, escaped alphanumerics, and raw characters, interpreting `\a`, `\x` and other sequences. The 4 trailing `\prg_do_nothing:` are needed because some functions defined later look up to 4 tokens ahead. Before ending, make sure that any `\c{...}` is properly closed. No need to check that brackets are closed properly since `\__regex_compile_end:` does that. However, catch the case of a trailing `\cL` construction.

```
\cs_new_protected:Npn \__regex_compile:n #1
  {
    \__regex_compile:w
      \__regex_standard_escapechar:
      \int_set_eq:NN \l__regex_mode_int \c__regex_outer_mode_int
      \__regex_escape_use:nnnn
        {
          \__regex_char_if_special:NTF ##1
            \__regex_compile_special:N \__regex_compile_raw:N ##1
        }
        {
          \__regex_char_if_alphanumeric:NTF ##1
            \__regex_compile_escaped:N \__regex_compile_raw:N ##1
        }
        { \__regex_compile_raw:N ##1 }
        { #1 }
      \prg_do_nothing: \prg_do_nothing:
      \prg_do_nothing: \prg_do_nothing:
      \int_compare:nNnT \l__regex_mode_int = \c__regex_catcode_mode_int
        { \msg_error:nn { regex } { c-trailing } }
      \int_compare:nNnT \l__regex_mode_int < \c__regex_outer_mode_int
        {
          \msg_error:nn { regex } { c-missing-rbrace }
          \__regex_compile_end_cs:
          \prg_do_nothing: \prg_do_nothing:
          \prg_do_nothing: \prg_do_nothing:
        }
    \__regex_compile_end:
  }
```

(*__regex_compile:n* 定义结束。)

__regex_compile_use:n

Use a regex, regardless of whether it is given as a string (in which case we need to compile) or as a regex variable. This is used for `\regex_match_case:nn` and related functions to allow a mixture of explicit regex and regex variables.

```
\cs_new_protected:Npn \__regex_compile_use:n #1
  {
    \tl_if_single_token:nT {#1}
      {
        \exp_after:wN \__regex_compile_use_aux:w
        \token_to_meaning:N #1 ~ \q__regex_nil
      }
    \__regex_compile:n {#1} \l__regex_internal_regex
  }
\cs_new_protected:Npn \__regex_compile_use_aux:w #1 ~ #2 \q__regex_nil
  {
    \str_if_eq:nnT { #1 ~ } { macro:->\__regex_branch:n }
      { \use_ii:nnn }
  }
```

(*__regex_compile_use:n* 定义结束。)

__regex_compile_escaped:N
__regex_compile_special:N

If the special character or escaped alphanumeric has a particular meaning in regexes, the corresponding function is used. Otherwise, it is interpreted as a raw character. We distinguish special characters from escaped alphanumeric characters because they behave differently when appearing as an end-point of a range.

```
\cs_new_protected:Npn \__regex_compile_special:N #1
  {
    \cs_if_exist_use:cF { __regex_compile_#1: }
      { \__regex_compile_raw:N #1 }
  }
\cs_new_protected:Npn \__regex_compile_escaped:N #1
  {
    \cs_if_exist_use:cF { __regex_compile_/#1: }
      { \__regex_compile_raw:N #1 }
  }
```

(*__regex_compile_escaped:N* 和 *__regex_compile_special:N* 定义结束。)

__regex_compile_one:n This is used after finding one “test”, such as \d, or a raw character. If that followed a catcode test (*e.g.*, \cL), then restore the mode. If we are not in a class, then the test is “standalone”, and we need to add __regex_class:NnnnN and search for quantifiers. In any case, insert the test, possibly together with a catcode test if appropriate.

```
\cs_new_protected:Npn \__regex_compile_one:n #1
  {
    \__regex_mode_quit_c:
    \__regex_if_in_class:TF { }
      {
        \tl_build_put_right:Nn \l__regex_build_tl
          { \__regex_class:NnnnN \c_true_bool { \if_false: } \fi: }
      }
    \tl_build_put_right:Ne \l__regex_build_tl
      {
        \if_int_compare:w \l__regex_catcodes_int <
          \c__regex_all_catcodes_int
          \__regex_item_catcode:nT { \int_use:N \l__regex_catcodes_int }
            { \exp_not:N \exp_not:n {#1} }
        \else:
          \exp_not:N \exp_not:n {#1}
        \fi:
      }
    \int_set_eq:NN \l__regex_catcodes_int \l__regex_default_catcodes_int
    \__regex_if_in_class:TF { } { \__regex_compile_quantifier:w }
  }
```

(*__regex_compile_one:n* 定义结束。)

__regex_compile_abort_tokens:n
__regex_compile_abort_tokens:e

This function places the collected tokens back in the input stream, each as a raw character. Spaces are not preserved.

```
\cs_new_protected:Npn \__regex_compile_abort_tokens:n #1
  {
    \use:e
      {
        \exp_args:No \tl_map_function:nN { \tl_to_str:n {#1} }
          \__regex_compile_raw:N
      }
  }
\cs_generate_variant:Nn \__regex_compile_abort_tokens:n { e }
```

(*__regex_compile_abort_tokens:n* 定义结束。)

9.3.5 Quantifiers

__regex_compile_if_quantifier:TFw

This looks ahead and checks whether there are any quantifier (special character equal to either of ?+*{). This is useful for the \u and \ur escape sequences.

```
\cs_new_protected:Npn \__regex_compile_if_quantifier:TFw #1#2#3#4
  {
    \token_if_eq_meaning:NNTF #3 \__regex_compile_special:N
      { \cs_if_exist:cTF { __regex_compile_quantifier_#4:w } }
      { \use_ii:nn }
    {#1} {#2} #3 #4
  }
```

(__*regex_compile_if_quantifier:TFw* 定义结束。)

__regex_compile_quantifier:w

This looks ahead and finds any quantifier (special character equal to either of ?+*{).

```
\cs_new_protected:Npn \__regex_compile_quantifier:w #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_compile_special:N
      {
        \cs_if_exist_use:cF { __regex_compile_quantifier_#2:w }
          { \__regex_compile_quantifier_none: #1 #2 }
      }
      { \__regex_compile_quantifier_none: #1 #2 }
  }
```

(__*regex_compile_quantifier:w* 定义结束。)

__regex_compile_quantifier_none:
__regex_compile_quantifier_abort:eNN

Those functions are called whenever there is no quantifier, or a braced construction is invalid (equivalent to no quantifier, and whatever characters were grabbed are left raw).

```
\cs_new_protected:Npn \__regex_compile_quantifier_none:
  {
    \tl_build_put_right:Nn \l__regex_build_tl
      { \if_false: { \fi: } { 1 } { 0 } \c_false_bool }
  }
\cs_new_protected:Npn \__regex_compile_quantifier_abort:eNN #1#2#3
  {
    \__regex_compile_quantifier_none:
    \msg_warning:nnee { regex } { invalid-quantifier } {#1} {#3}
    \__regex_compile_abort_tokens:e {#1}
    #2 #3
  }
```

(*__regex_compile_quantifier_none:* 和 *__regex_compile_quantifier_abort:eNN* 定义结束。)

__regex_compile_quantifier_lazyness:nnNN

Once the "main" quantifier (`?`, `*`, `+` or a braced construction) is found, we check whether it is lazy (followed by a question mark). We then add to the compiled regex a closing brace (ending `\__regex_class:NnnnN` and friends), the start-point of the range, its end-point, and a boolean, `true` for lazy and `false` for greedy operators.

```
\cs_new_protected:Npn \__regex_compile_quantifier_lazyness:nnNN #1#2#3#4
  {
    \__regex_two_if_eq:NNNNTF #3 #4 \__regex_compile_special:N ?
      {
        \tl_build_put_right:Nn \l__regex_build_tl
          { \if_false: { \fi: } { #1 } { #2 } \c_true_bool }
      }
      {
        \tl_build_put_right:Nn \l__regex_build_tl
          { \if_false: { \fi: } { #1 } { #2 } \c_false_bool }
        #3 #4
      }
  }
```

(*__regex_compile_quantifier_lazyness:nnNN* 定义结束。)

__regex_compile_quantifier_?:w
__regex_compile_quantifier_*:w
__regex_compile_quantifier_+:w

For each "basic" quantifier, `?`, `*`, `+`, feed the correct arguments to `\__regex_compile_quantifier_lazyness:nnNN`, -1 means that there is no upper bound on the number of repetitions.

```
\cs_new_protected:cpn { __regex_compile_quantifier_?:w }
  { \__regex_compile_quantifier_lazyness:nnNN { 0 } { 1 } }
\cs_new_protected:cpn { __regex_compile_quantifier_*:w }
  { \__regex_compile_quantifier_lazyness:nnNN { 0 } { -1 } }
\cs_new_protected:cpn { __regex_compile_quantifier_+:w }
  { \__regex_compile_quantifier_lazyness:nnNN { 1 } { -1 } }
```

(*__regex_compile_quantifier_?:w*, *__regex_compile_quantifier_*:w*, 和 *__regex_compile_quantifier_+:w* 定义结束。)

__regex_compile_quantifier_{:w
__regex_compile_quantifier_braced_auxi:w
__regex_compile_quantifier_braced_auxii:w
__regex_compile_quantifier_braced_auxiii:w

Three possible syntaxes: `{`⟨*int*⟩`}`, `{`⟨*int*⟩`,}`, or `{`⟨*int*⟩`,`⟨*int*⟩`}`. Any other syntax causes us to abort and put whatever we collected back in the input stream, as `raw` characters, including the opening brace. Grab a number into `\l__regex_internal_a_int`. If the number is followed by a right brace, the range is $[a,a]$. If followed by a comma, grab one more number, and call the `_ii` or `_iii` auxiliary. Those auxiliaries check for a closing brace, leading to the range $[a,\infty]$ or $[a,b]$, encoded as $\{a\}\{-1\}$ and $\{a\}\{b-a\}$.

```
\cs_new_protected:cpn { __regex_compile_quantifier_ \c_left_brace_str :w }
  {
    \__regex_get_digits:NTFw \l__regex_internal_a_int
      { \__regex_compile_quantifier_braced_auxi:w }
      { \__regex_compile_quantifier_abort:eNN { \c_left_brace_str } }
  }
\cs_new_protected:Npn \__regex_compile_quantifier_braced_auxi:w #1#2
  {
    \str_case_e:nnF { #1 #2 }
      {
        { \__regex_compile_special:N \c_right_brace_str }
          {
            \exp_args:No \__regex_compile_quantifier_lazyness:nnNN
              { \int_use:N \l__regex_internal_a_int } { 0 }
          }
        { \__regex_compile_special:N , }
          {
            \__regex_get_digits:NTFw \l__regex_internal_b_int
              { \__regex_compile_quantifier_braced_auxiii:w }
              { \__regex_compile_quantifier_braced_auxii:w }
          }
      }
      {
        \__regex_compile_quantifier_abort:eNN
          { \c_left_brace_str \int_use:N \l__regex_internal_a_int }
        #1 #2
      }
  }
\cs_new_protected:Npn \__regex_compile_quantifier_braced_auxii:w #1#2
  {
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_special:N \c_right_brace_str
      {
        \exp_args:No \__regex_compile_quantifier_lazyness:nnNN
          { \int_use:N \l__regex_internal_a_int } { -1 }
      }
      {
        \__regex_compile_quantifier_abort:eNN
          { \c_left_brace_str \int_use:N \l__regex_internal_a_int , }
        #1 #2
      }
  }
\cs_new_protected:Npn \__regex_compile_quantifier_braced_auxiii:w #1#2
```

```
  {
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_special:N \c_right_brace_str
      {
        \if_int_compare:w \l__regex_internal_a_int >
          \l__regex_internal_b_int
          \msg_error:nnee { regex } { backwards-quantifier }
            { \int_use:N \l__regex_internal_a_int }
            { \int_use:N \l__regex_internal_b_int }
          \int_zero:N \l__regex_internal_b_int
        \else:
          \int_sub:Nn \l__regex_internal_b_int \l__regex_internal_a_int
        \fi:
        \exp_args:Noo \__regex_compile_quantifier_lazyness:nnNN
          { \int_use:N \l__regex_internal_a_int }
          { \int_use:N \l__regex_internal_b_int }
      }
      {
        \__regex_compile_quantifier_abort:eNN
          {
            \c_left_brace_str
            \int_use:N \l__regex_internal_a_int ,
            \int_use:N \l__regex_internal_b_int
          }
        #1 #2
      }
  }
```

(*__regex_compile_quantifier_{:w 以及其它的定义结束。*)

9.3.6 Raw characters

__regex_compile_raw_error:N Within character classes, and following catcode tests, some escaped alphanumeric sequences such as \b do not have any meaning. They are replaced by a raw character, after spitting out an error.

```
\cs_new_protected:Npn \__regex_compile_raw_error:N #1
  {
    \msg_error:nne { regex } { bad-escape } {#1}
    \__regex_compile_raw:N #1
  }
```

(*__regex_compile_raw_error:N 定义结束。*)

__regex_compile_raw:N

If we are in a character class and the next character is an unescaped dash, this denotes a range. Otherwise, the current character #1 matches itself.

```
\cs_new_protected:Npn \__regex_compile_raw:N #1#2#3
  {
    \__regex_if_in_class:TF
      {
        \__regex_two_if_eq:NNNNTF #2 #3 \__regex_compile_special:N -
          { \__regex_compile_range:Nw #1 }
          {
            \__regex_compile_one:n
              { \__regex_item_equal:n { \int_value:w `#1 } }
            #2 #3
          }
      }
      {
        \__regex_compile_one:n
          { \__regex_item_equal:n { \int_value:w `#1 } }
        #2 #3
      }
  }
```

（__regex_compile_raw:N 定义结束。）

__regex_compile_range:Nw
__regex_if_end_range:NNTF

We have just read a raw character followed by a dash; this should be followed by an end-point for the range. Valid end-points are: any raw character; any special character, except a right bracket. In particular, escaped characters are forbidden.

```
\prg_new_protected_conditional:Npnn \__regex_if_end_range:NN #1#2 { TF }
  {
    \if_meaning:w \__regex_compile_raw:N #1
      \prg_return_true:
    \else:
      \if_meaning:w \__regex_compile_special:N #1
        \if_charcode:w ] #2
          \prg_return_false:
        \else:
          \prg_return_true:
        \fi:
      \else:
        \prg_return_false:
      \fi:
    \fi:
  }
```

```
\cs_new_protected:Npn \__regex_compile_range:Nw #1#2#3
  {
    \__regex_if_end_range:NNTF #2 #3
      {
        \if_int_compare:w `#1 > `#3 \exp_stop_f:
          \msg_error:nnee { regex } { range-backwards } {#1} {#3}
        \else:
          \tl_build_put_right:Ne \l__regex_build_tl
            {
              \if_int_compare:w `#1 = `#3 \exp_stop_f:
                \__regex_item_equal:n
              \else:
                \__regex_item_range:nn { \int_value:w `#1 }
              \fi:
              { \int_value:w `#3 }
            }
        \fi:
      }
      {
        \msg_warning:nnee { regex } { range-missing-end }
          {#1} { \c_backslash_str #3 }
        \tl_build_put_right:Ne \l__regex_build_tl
          {
            \__regex_item_equal:n { \int_value:w `#1 \exp_stop_f: }
            \__regex_item_equal:n { \int_value:w `- \exp_stop_f: }
          }
        #2#3
      }
  }
```

(*__regex_compile_range:Nw* 和 *__regex_if_end_range:NNTF* 定义结束。)

9.3.7 Character properties

__regex_compile_.:
__regex_prop_.:

In a class, the dot has no special meaning. Outside, insert __regex_prop_.:, which matches any character or control sequence, and refuses −2 (end-marker).

```
\cs_new_protected:cpe { __regex_compile_.: }
  {
    \exp_not:N \__regex_if_in_class:TF
      { \__regex_compile_raw:N . }
      { \__regex_compile_one:n \exp_not:c { __regex_prop_.: } }
  }
\cs_new_protected:cpn { __regex_prop_.: }
```

```
  {
    \if_int_compare:w \l__regex_curr_char_int > - 2 \exp_stop_f:
      \exp_after:wN \__regex_break_true:w
    \fi:
  }
```

(*__regex_compile_.: 和 __regex_prop_.:* 定义结束。)

__regex_compile_/d:
__regex_compile_/D:
__regex_compile_/h:
__regex_compile_/H:
__regex_compile_/s:
__regex_compile_/S:
__regex_compile_/v:
__regex_compile_/V:
__regex_compile_/w:
__regex_compile_/W:
__regex_compile_/N:

The constants `\__regex_prop_d:`, *etc.* hold a list of tests which match the corresponding character class, and jump to the `\__regex_break_point:TF` marker. As for a normal character, we check for quantifiers.

```
\cs_set_protected:Npn \__regex_tmp:w #1#2
  {
    \cs_new_protected:cpe { __regex_compile_/#1: }
      { \__regex_compile_one:n \exp_not:c { __regex_prop_#1: } }
    \cs_new_protected:cpe { __regex_compile_/#2: }
      {
        \__regex_compile_one:n
          { \__regex_item_reverse:n { \exp_not:c { __regex_prop_#1: } } }
      }
  }
\__regex_tmp:w d D
\__regex_tmp:w h H
\__regex_tmp:w s S
\__regex_tmp:w v V
\__regex_tmp:w w W
\cs_new_protected:cpn { __regex_compile_/N: }
  { \__regex_compile_one:n \__regex_prop_N: }
```

(*__regex_compile_/d:* 以及其它的定义结束。)

9.3.8 Anchoring and simple assertions

__regex_compile_anchor_letter:NNN
__regex_compile_/A:
__regex_compile_/G:
__regex_compile_/Z:
__regex_compile_/z:
__regex_compile_/b:
__regex_compile_/B:
__regex_compile_^:
__regex_compile_$:

In modes where assertions are forbidden, anchors such as `\A` produce an error (`\A` is invalid in classes); otherwise they add an `\__regex_assertion:Nn` test as appropriate (the only negative assertion is `\B`). The test functions are defined later. The implementation for `$` and `^` is only different from `\A` etc because these are valid in a class.

```
\cs_new_protected:Npn \__regex_compile_anchor_letter:NNN #1#2#3
  {
    \__regex_if_in_class_or_catcode:TF { \__regex_compile_raw_error:N #1 }
      {
        \tl_build_put_right:Nn \l__regex_build_tl
          { \__regex_assertion:Nn #2 {#3} }
      }
  }
\cs_new_protected:cpn { __regex_compile_/A: }
  { \__regex_compile_anchor_letter:NNN A \c_true_bool \__regex_A_test: }
\cs_new_protected:cpn { __regex_compile_/G: }
  { \__regex_compile_anchor_letter:NNN G \c_true_bool \__regex_G_test: }
\cs_new_protected:cpn { __regex_compile_/Z: }
  { \__regex_compile_anchor_letter:NNN Z \c_true_bool \__regex_Z_test: }
\cs_new_protected:cpn { __regex_compile_/z: }
  { \__regex_compile_anchor_letter:NNN z \c_true_bool \__regex_Z_test: }
\cs_new_protected:cpn { __regex_compile_/b: }
  { \__regex_compile_anchor_letter:NNN b \c_true_bool \__regex_b_test: }
\cs_new_protected:cpn { __regex_compile_/B: }
  { \__regex_compile_anchor_letter:NNN B \c_false_bool \__regex_b_test: }
\cs_set_protected:Npn \__regex_tmp:w #1#2
  {
    \cs_new_protected:cpn { __regex_compile_#1: }
      {
        \__regex_if_in_class_or_catcode:TF { \__regex_compile_raw:N #1 }
          {
            \tl_build_put_right:Nn \l__regex_build_tl
              { \__regex_assertion:Nn \c_true_bool {#2} }
          }
      }
  }
\exp_args:Ne \__regex_tmp:w { \iow_char:N \^ } { \__regex_A_test: }
\exp_args:Ne \__regex_tmp:w { \iow_char:N \$ } { \__regex_Z_test: }
```

（__*regex_compile_anchor_letter:NNN* 以及其它的定义结束。）

9.3.9 Character classes

__regex_compile_]: Outside a class, right brackets have no meaning. In a class, change the mode ($m \to (m-15)/13$, truncated) to reflect the fact that we are leaving the class. Look for quantifiers, unless we are still in a class after leaving one (the case of `[...\cL[...]...]`). quantifiers.

```
\cs_new_protected:cpn { __regex_compile_]: }
  {
    \__regex_if_in_class:TF
      {
        \if_int_compare:w \l__regex_mode_int >
          \c__regex_catcode_in_class_mode_int
          \tl_build_put_right:Nn \l__regex_build_tl { \if_false: { \fi: } }
        \fi:
        \tex_advance:D \l__regex_mode_int - 15 \exp_stop_f:
        \tex_divide:D \l__regex_mode_int 13 \exp_stop_f:
        \if_int_odd:w \l__regex_mode_int \else:
          \exp_after:wN \__regex_compile_quantifier:w
        \fi:
      }
      { \__regex_compile_raw:N ] }
  }
```

(*__regex_compile_]:* 定义结束。)

__regex_compile_[: In a class, left brackets might introduce a POSIX character class, or mean nothing. Immediately following `\c`⟨*category*⟩, we must insert the appropriate catcode test, then parse the class; we pre-expand the catcode as an optimization. Otherwise (modes 0, −2 and −6) just parse the class. The mode is updated later.

```
\cs_new_protected:cpn { __regex_compile_[: }
  {
    \__regex_if_in_class:TF
      { \__regex_compile_class_posix_test:w }
      {
        \__regex_if_within_catcode:TF
          {
            \exp_after:wN \__regex_compile_class_catcode:w
              \int_use:N \l__regex_catcodes_int ;
          }
          { \__regex_compile_class_normal:w }
      }
  }
```

(*__regex_compile_[:* 定义结束。)

__regex_compile_class_normal:w In the "normal" case, we insert `\__regex_class:NnnnN` ⟨*boolean*⟩ in the compiled code. The ⟨*boolean*⟩ is true for positive classes, and false for negative classes, characterized by a leading `^`. The auxiliary `\__regex_compile_class:TFNN` also checks for a leading `]` which has a special meaning.

```
\cs_new_protected:Npn \__regex_compile_class_normal:w
  {
    \__regex_compile_class:TFNN
```

```
      { \__regex_class:NnnnN \c_true_bool }
      { \__regex_class:NnnnN \c_false_bool }
  }
```

(__*regex_compile_class_normal:w* 定义结束。)

__regex_compile_class_catcode:w

This function is called for a left bracket in modes 2 or 6 (catcode test, and catcode test within a class). In mode 2 the whole construction needs to be put in a class (like single character). Then determine if the class is positive or negative, inserting `\__regex_item_catcode:nT` or the `reverse` variant as appropriate, each with the current catcodes bitmap `#1` as an argument, and reset the catcodes.

```
\cs_new_protected:Npn \__regex_compile_class_catcode:w #1;
  {
    \if_int_compare:w \l__regex_mode_int = \c__regex_catcode_mode_int
      \tl_build_put_right:Nn \l__regex_build_tl
        { \__regex_class:NnnnN \c_true_bool { \if_false: } \fi: }
    \fi:
    \int_set_eq:NN \l__regex_catcodes_int \l__regex_default_catcodes_int
    \__regex_compile_class:TFNN
      { \__regex_item_catcode:nT {#1} }
      { \__regex_item_catcode_reverse:nT {#1} }
  }
```

(__*regex_compile_class_catcode:w* 定义结束。)

__regex_compile_class:TFNN
__regex_compile_class:NN

If the first character is `^`, then the class is negative (use `#2`), otherwise it is positive (use `#1`). If the next character is a right bracket, then it should be changed to a raw one.

```
\cs_new_protected:Npn \__regex_compile_class:TFNN #1#2#3#4
  {
    \l__regex_mode_int = \int_value:w \l__regex_mode_int 3 \exp_stop_f:
    \__regex_two_if_eq:NNNNTF #3 #4 \__regex_compile_special:N ^
      {
        \tl_build_put_right:Nn \l__regex_build_tl { #2 { \if_false: } \fi: }
        \__regex_compile_class:NN
      }
      {
        \tl_build_put_right:Nn \l__regex_build_tl { #1 { \if_false: } \fi: }
        \__regex_compile_class:NN #3 #4
      }
  }
\cs_new_protected:Npn \__regex_compile_class:NN #1#2
```

```
  {
    \token_if_eq_charcode:NNTF #2 ]
      { \__regex_compile_raw:N #2 }
      { #1 #2 }
  }
```

(*__regex_compile_class:TFNN* 和 *__regex_compile_class:NN* 定义结束。)

__regex_compile_class_posix_test:w
__regex_compile_class_posix:NNNNw
__regex_compile_class_posix_loop:w
__regex_compile_class_posix_end:w

Here we check for a syntax such as `[:alpha:]`. We also detect `[=` and `[.` which have a meaning in POSIX regular expressions, but are not implemented in l3regex. In case we see `[:`, grab raw characters until hopefully reaching `:]`. If that's missing, or the POSIX class is unknown, abort. If all is right, add the test to the current class, with an extra `\__regex_item_reverse:n` for negative classes (we make sure to wrap its argument in braces otherwise `\regex_show:N` would not recognize the regex as valid).

```
\cs_new_protected:Npn \__regex_compile_class_posix_test:w #1#2
  {
    \token_if_eq_meaning:NNT \__regex_compile_special:N #1
      {
        \str_case:nn { #2 }
          {
            : { \__regex_compile_class_posix:NNNNw }
            = {
                \msg_warning:nne { regex }
                  { posix-unsupported } { = }
              }
            . {
                \msg_warning:nne { regex }
                  { posix-unsupported } { . }
              }
          }
      }
    \__regex_compile_raw:N [ #1 #2
  }
\cs_new_protected:Npn \__regex_compile_class_posix:NNNNw #1#2#3#4#5#6
  {
    \__regex_two_if_eq:NNNNTF #5 #6 \__regex_compile_special:N ^
      {
        \bool_set_false:N \l__regex_internal_bool
        \__kernel_tl_set:Ne \l__regex_internal_a_tl { \if_false: } \fi:
          \__regex_compile_class_posix_loop:w
      }
      {
        \bool_set_true:N \l__regex_internal_bool
        \__kernel_tl_set:Ne \l__regex_internal_a_tl { \if_false: } \fi:
          \__regex_compile_class_posix_loop:w #5 #6
      }
  }
\cs_new:Npn \__regex_compile_class_posix_loop:w #1#2
  {
    \token_if_eq_meaning:NNTF \__regex_compile_raw:N #1
      { #2 \__regex_compile_class_posix_loop:w }
      { \if_false: { \fi: } \__regex_compile_class_posix_end:w #1 #2 }
  }
\cs_new_protected:Npn \__regex_compile_class_posix_end:w #1#2#3#4
  {
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_special:N :
      { \__regex_two_if_eq:NNNNTF #3 #4 \__regex_compile_special:N ] }
      { \use_ii:nn }
      {
        \cs_if_exist:cTF { __regex_posix_ \l__regex_internal_a_tl : }
          {
            \__regex_compile_one:n
              {
                \bool_if:NTF \l__regex_internal_bool \use:n \__regex_item_reverse:n
                { \exp_not:c { __regex_posix_ \l__regex_internal_a_tl : } }
              }
          }
          {
            \msg_warning:nne { regex } { posix-unknown }
              { \l__regex_internal_a_tl }
            \__regex_compile_abort_tokens:e
              {
                [: \bool_if:NF \l__regex_internal_bool { ^ }
                \l__regex_internal_a_tl :]
              }
          }
      }
      {
        \msg_error:nnee { regex } { posix-missing-close }
          { [: \l__regex_internal_a_tl } { #2 #4 }
        \__regex_compile_abort_tokens:e { [: \l__regex_internal_a_tl }
        #1 #2 #3 #4
      }
  }
```

(__regex_compile_class_posix_test:w 以及其它的定义结束。)

9.3.10 Groups and alternations

__regex_compile_group_begin:N
__regex_compile_group_end:

The contents of a regex group are turned into compiled code in `\l__regex_build_tl`, which ends up with items of the form `\__regex_branch:n {`⟨*concatenation*⟩`}`. This construction is done using `\tl_build_`… functions within a TEX group, which automatically makes sure that options (case-sensitivity and default catcode) are reset at the end of the group. The argument `#1` is `\__regex_group:nnnN` or a variant thereof. A small subtlety to support `\cL(abc)` as a shorthand for `(\cLa\cLb\cLc)`: exit any pending catcode test, save the category code at the start of the group as the default catcode for that group, and make sure that the catcode is restored to the default outside the group.

```
\cs_new_protected:Npn \__regex_compile_group_begin:N #1
  {
    \tl_build_put_right:Nn \l__regex_build_tl { #1 { \if_false: } \fi: }
    \__regex_mode_quit_c:
    \group_begin:
      \tl_build_begin:N \l__regex_build_tl
      \int_set_eq:NN \l__regex_default_catcodes_int \l__regex_catcodes_int
      \int_incr:N \l__regex_group_level_int
      \tl_build_put_right:Nn \l__regex_build_tl
        { \__regex_branch:n { \if_false: } \fi: }
  }
\cs_new_protected:Npn \__regex_compile_group_end:
  {
    \if_int_compare:w \l__regex_group_level_int > \c_zero_int
        \tl_build_put_right:Nn \l__regex_build_tl { \if_false: { \fi: } }
        \tl_build_end:N \l__regex_build_tl
        \exp_args:NNNe
      \group_end:
      \tl_build_put_right:Nn \l__regex_build_tl { \l__regex_build_tl }
      \int_set_eq:NN \l__regex_catcodes_int \l__regex_default_catcodes_int
      \exp_after:wN \__regex_compile_quantifier:w
    \else:
      \msg_warning:nn { regex } { extra-rparen }
      \exp_after:wN \__regex_compile_raw:N \exp_after:wN )
    \fi:
  }
```

(*__regex_compile_group_begin:N* 和 *__regex_compile_group_end:* 定义结束。)

__regex_compile_(: In a class, parentheses are not special. In a catcode test inside a class, a left parenthesis gives an error, to catch `[a\cL(bcd)e]`. Otherwise check for a `?`, denoting special groups, and run the code for the corresponding special group.

```
\cs_new_protected:cpn { __regex_compile_(: }
  {
    \__regex_if_in_class:TF { \__regex_compile_raw:N ( }
      {
        \if_int_compare:w \l__regex_mode_int =
          \c__regex_catcode_in_class_mode_int
          \msg_error:nn { regex } { c-lparen-in-class }
          \exp_after:wN \__regex_compile_raw:N \exp_after:wN (
        \else:
          \exp_after:wN \__regex_compile_lparen:w
        \fi:
      }
  }
\cs_new_protected:Npn \__regex_compile_lparen:w #1#2#3#4
  {
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_special:N ?
      {
        \cs_if_exist_use:cF
          { __regex_compile_special_group_\token_to_str:N #4 :w }
          {
            \msg_warning:nne { regex } { special-group-unknown }
              { (? #4 }
            \__regex_compile_group_begin:N \__regex_group:nnnN
              \__regex_compile_raw:N ? #3 #4
          }
      }
      {
        \__regex_compile_group_begin:N \__regex_group:nnnN
          #1 #2 #3 #4
      }
  }
```

(*__regex_compile_(:* 定义结束。)

__regex_compile_|: In a class, the pipe is not special. Otherwise, end the current branch and open another one.

```
\cs_new_protected:cpn { __regex_compile_|: }
```

```
  {
    \__regex_if_in_class:TF { \__regex_compile_raw:N | }
      {
        \tl_build_put_right:Nn \l__regex_build_tl
          { \if_false: { \fi: } \__regex_branch:n { \if_false: } \fi: }
      }
  }
```

(*__regex_compile_|:* 定义结束。)

__regex_compile_):

Within a class, parentheses are not special. Outside, close a group.

```
\cs_new_protected:cpn { __regex_compile_): }
  {
    \__regex_if_in_class:TF { \__regex_compile_raw:N ) }
      { \__regex_compile_group_end: }
  }
```

(*__regex_compile_):* 定义结束。)

__regex_compile_special_group_::w
__regex_compile_special_group_|:w

Non-capturing, and resetting groups are easy to take care of during compilation; for those groups, the harder parts come when building.

```
\cs_new_protected:cpn { __regex_compile_special_group_::w }
  { \__regex_compile_group_begin:N \__regex_group_no_capture:nnnN }
\cs_new_protected:cpn { __regex_compile_special_group_|:w }
  { \__regex_compile_group_begin:N \__regex_group_resetting:nnnN }
```

(*__regex_compile_special_group_::w* 和 *__regex_compile_special_group_|:w* 定义结束。)

__regex_compile_special_group_i:w
__regex_compile_special_group_-:w

The match can be made case-insensitive by setting the option with (?i); the original behaviour is restored by (?-i). This is the only supported option.

```
\cs_new_protected:Npn \__regex_compile_special_group_i:w #1#2
  {
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_special:N )
      {
        \cs_set:Npn \__regex_item_equal:n
          { \__regex_item_caseless_equal:n }
        \cs_set:Npn \__regex_item_range:nn
          { \__regex_item_caseless_range:nn }
      }
      {
        \msg_warning:nne { regex } { unknown-option } { (?i #2 }
        \__regex_compile_raw:N (
        \__regex_compile_raw:N ?
        \__regex_compile_raw:N i
        #1 #2
      }
  }
\cs_new_protected:cpn { __regex_compile_special_group_-:w } #1#2#3#4
  {
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_raw:N i
      { \__regex_two_if_eq:NNNNTF #3 #4 \__regex_compile_special:N ) }
      { \use_ii:nn }
      {
        \cs_set:Npn \__regex_item_equal:n
          { \__regex_item_caseful_equal:n }
        \cs_set:Npn \__regex_item_range:nn
          { \__regex_item_caseful_range:nn }
      }
      {
        \msg_warning:nne { regex } { unknown-option } { (?-#2#4 }
        \__regex_compile_raw:N (
        \__regex_compile_raw:N ?
        \__regex_compile_raw:N -
        #1 #2 #3 #4
      }
  }
```

(*__regex_compile_special_group_i:w* 和 *__regex_compile_special_group_-:w* 定义结束。)

9.3.11 Catcodes and csnames

__regex_compile_/c:
__regex_compile_c_test:NN

The \c escape sequence can be followed by a capital letter representing a character category, by a left bracket which starts a list of categories, or by a brace group holding a regular expression for a control sequence name. Otherwise, raise an error.

```
\cs_new_protected:cpn { __regex_compile_/c: }
  { \__regex_chk_c_allowed:T { \__regex_compile_c_test:NN } }
\cs_new_protected:Npn \__regex_compile_c_test:NN #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_compile_raw:N
      {
        \int_if_exist:cTF { c__regex_catcode_#2_int }
          {
            \int_set_eq:Nc \l__regex_catcodes_int
              { c__regex_catcode_#2_int }
            \l__regex_mode_int
```

```
       = \if_case:w \l__regex_mode_int
         \c__regex_catcode_mode_int
        \else:
         \c__regex_catcode_in_class_mode_int
        \fi:
      \token_if_eq_charcode:NNT C #2 { \__regex_compile_c_C:NN }
     }
   }
   { \cs_if_exist_use:cF { __regex_compile_c_#2:w } }
     {
      \msg_error:nne { regex } { c-missing-category } {#2}
      #1 #2
     }
 }
```

(__*regex_compile_/c:* 和 __*regex_compile_c_test:NN* 定义结束。)

__regex_compile_c_C:NN

If \cC is not followed by . or (...) then complain because that construction cannot match anything, except in cases like \cC[\c{...}], where it has no effect.

```
\cs_new_protected:Npn \__regex_compile_c_C:NN #1#2
 {
  \token_if_eq_meaning:NNTF #1 \__regex_compile_special:N
   {
    \token_if_eq_charcode:NNTF #2 .
     { \use_none:n }
     { \token_if_eq_charcode:NNF #2 ( } % )
   }
   { \use:n }
  { \msg_error:nnn { regex } { c-C-invalid } {#2} }
  #1 #2
 }
```

(__*regex_compile_c_C:NN* 定义结束。)

__regex_compile_c_[:w
__regex_compile_c_lbrack_loop:NN
__regex_compile_c_lbrack_add:N
__regex_compile_c_lbrack_end:

When encountering \c[, the task is to collect uppercase letters representing character categories. First check for ^ which negates the list of category codes.

```
\cs_new_protected:cpn { __regex_compile_c_[:w } #1#2
 {
  \l__regex_mode_int
   = \if_case:w \l__regex_mode_int
     \c__regex_catcode_mode_int
    \else:
     \c__regex_catcode_in_class_mode_int
```

```
        \fi:
    \int_zero:N \l__regex_catcodes_int
    \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_special:N ^
      {
        \bool_set_false:N \l__regex_catcodes_bool
        \__regex_compile_c_lbrack_loop:NN
      }
      {
        \bool_set_true:N \l__regex_catcodes_bool
        \__regex_compile_c_lbrack_loop:NN
        #1 #2
      }
  }
\cs_new_protected:Npn \__regex_compile_c_lbrack_loop:NN #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_compile_raw:N
      {
        \int_if_exist:cTF { c__regex_catcode_#2_int }
          {
            \exp_args:Nc \__regex_compile_c_lbrack_add:N
              { c__regex_catcode_#2_int }
            \__regex_compile_c_lbrack_loop:NN
          }
      }
      {
        \token_if_eq_charcode:NNTF #2 ]
          { \__regex_compile_c_lbrack_end: }
      }
          {
            \msg_error:nne { regex } { c-missing-rbrack } {#2}
            \__regex_compile_c_lbrack_end:
            #1 #2
          }
  }
\cs_new_protected:Npn \__regex_compile_c_lbrack_add:N #1
  {
    \if_int_odd:w \int_eval:n { \l__regex_catcodes_int / #1 } \exp_stop_f:
    \else:
      \int_add:Nn \l__regex_catcodes_int {#1}
    \fi:
  }
\cs_new_protected:Npn \__regex_compile_c_lbrack_end:
  {
    \if_meaning:w \c_false_bool \l__regex_catcodes_bool
      \int_set:Nn \l__regex_catcodes_int
        { \c__regex_all_catcodes_int - \l__regex_catcodes_int }
    \fi:
  }
```

(*__regex_compile_c_[:w* 以及其它的定义结束。)

__regex_compile_c_{:

The case of a left brace is easy, based on what we have done so far: in a group, compile the regular expression, after changing the mode to forbid nesting `\c`. Additionally, disable submatch tracking since groups don't escape the scope of `\c{...}`.

```
\cs_new_protected:cpn { __regex_compile_c_ \c_left_brace_str :w }
  {
    \__regex_compile:w
      \__regex_disable_submatches:
      \l__regex_mode_int
        = \if_case:w \l__regex_mode_int
            \c__regex_cs_mode_int
          \else:
            \c__regex_cs_in_class_mode_int
          \fi:
  }
```

(*__regex_compile_c_{:* 定义结束。)

__regex_compile_{:

We forbid unescaped left braces inside a `\c{...}` escape because they otherwise lead to the confusing question of whether the first right brace in `\c{{}x}` should end `\c` or whether one should match braces.

```
\cs_new_protected:cpn { __regex_compile_ \c_left_brace_str : }
  {
    \__regex_if_in_cs:TF
      { \msg_error:nnn { regex } { cu-lbrace } { c } }
      { \exp_after:wN \__regex_compile_raw:N \c_left_brace_str }
  }
```

(*__regex_compile_{:* 定义结束。)

__regex_cs
__regex_compile_}:
__regex_compile_end_cs:
__regex_compile_cs_aux:Nn
__regex_compile_cs_aux:NNnnnN

Non-escaped right braces are only special if they appear when compiling the regular expression for a csname, but not within a class: `\c{[{}]}` matches the control sequences `\{` and `\}`. So, end compiling the inner regex (this closes any dangling class or group). Then insert the corresponding test in the outer regex. As an optimization, if the control sequence test simply consists of several explicit possibilities (branches) then use `\__regex_item_exact_cs:n` with an argument consisting of all possibilities separated by `\scan_stop:`.

```
\flag_new:n { __regex_cs }
\cs_new_protected:cpn { __regex_compile_ \c_right_brace_str : }
  {
    \__regex_if_in_cs:TF
      { \__regex_compile_end_cs: }
      { \exp_after:wN \__regex_compile_raw:N \c_right_brace_str }
  }
\cs_new_protected:Npn \__regex_compile_end_cs:
  {
    \__regex_compile_end:
    \flag_clear:n { __regex_cs }
    \__kernel_tl_set:Ne \l__regex_internal_a_tl
      {
        \exp_after:wN \__regex_compile_cs_aux:Nn \l__regex_internal_regex
        \q__regex_nil \q__regex_nil \q__regex_recursion_stop
      }
    \exp_args:Ne \__regex_compile_one:n
      {
        \flag_if_raised:nTF { __regex_cs }
          { \__regex_item_cs:n { \exp_not:o \l__regex_internal_regex } }
          {
            \__regex_item_exact_cs:n
              { \tl_tail:N \l__regex_internal_a_tl }
          }
      }
  }
\cs_new:Npn \__regex_compile_cs_aux:Nn #1#2
  {
    \cs_if_eq:NNTF #1 \__regex_branch:n
      {
        \scan_stop:
        \__regex_compile_cs_aux:NNnnnN #2
        \q__regex_nil \q__regex_nil \q__regex_nil
        \q__regex_nil \q__regex_nil \q__regex_nil \q__regex_recursion_stop
        \__regex_compile_cs_aux:Nn
      }
      {
        \__regex_quark_if_nil:NF #1 { \flag_ensure_raised:n { __regex_cs } }
        \__regex_use_none_delimit_by_q_recursion_stop:w
      }
  }
\cs_new:Npn \__regex_compile_cs_aux:NNnnnN #1#2#3#4#5#6
  {
    \bool_lazy_all:nTF
      {
        { \cs_if_eq_p:NN #1 \__regex_class:NnnnN }
        {#2}
        { \tl_if_head_eq_meaning_p:nN {#3} \__regex_item_caseful_equal:n }
        { \int_compare_p:nNn { \tl_count:n {#3} } = { 2 } }
        { \int_compare_p:nNn {#5} = { 0 } }
      }
      {
        \prg_replicate:nn {#4}
          { \char_generate:nn { \use_ii:nn #3 } {12} }
        \__regex_compile_cs_aux:NNnnnN
      }
      {
        \__regex_quark_if_nil:NF #1
          {
            \flag_ensure_raised:n { __regex_cs }
            \__regex_use_i_delimit_by_q_recursion_stop:nw
          }
        \__regex_use_none_delimit_by_q_recursion_stop:w
      }
  }
```

(*__regex_cs* 以及其它的定义结束。)

9.3.12 Raw token lists with \u

__regex_compile_/u: The \u escape is invalid in classes and directly following a catcode test. Otherwise test for a following r (for \ur), and call an auxiliary responsible for finding the variable name.

```
\cs_new_protected:cpn { __regex_compile_/u: } #1#2
  {
    \__regex_if_in_class_or_catcode:TF
      { \__regex_compile_raw_error:N u #1 #2 }
      {
        \__regex_two_if_eq:NNNNTF #1 #2 \__regex_compile_raw:N r
          { \__regex_compile_u_brace:NNN \__regex_compile_ur_end: }
          { \__regex_compile_u_brace:NNN \__regex_compile_u_end: #1 #2 }
      }
  }
```

(__regex_compile_/u: 定义结束。)

__regex_compile_u_brace:NNN This enforces the presence of a left brace, then starts a loop to find the variable name.

```
\cs_new:Npn \__regex_compile_u_brace:NNN #1#2#3
  {
    \__regex_two_if_eq:NNNNTF #2 #3 \__regex_compile_special:N \c_left_brace_str
      {
        \tl_set:Nn \l__regex_internal_b_tl {#1}
        \__kernel_tl_set:Ne \l__regex_internal_a_tl { \if_false: } \fi:
        \__regex_compile_u_loop:NN
      }
      {
        \msg_error:nn { regex } { u-missing-lbrace }
        \token_if_eq_meaning:NNTF #1 \__regex_compile_ur_end:
          { \__regex_compile_raw:N u \__regex_compile_raw:N r }
          { \__regex_compile_raw:N u }
        #2 #3
      }
  }
```

(__regex_compile_u_brace:NNN 定义结束。)

__regex_compile_u_loop:NN We collect the characters for the argument of \u within an e-expanding assignment. In principle we could just wait to encounter a right brace, but this is unsafe: if the right brace was missing, then we would reach the end-markers of the regex, and continue, leading to obscure fatal errors. Instead, we only allow raw and special characters, and stop when encountering a special right brace, any escaped character, or the end-marker.

```
\cs_new:Npn \__regex_compile_u_loop:NN #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_compile_raw:N
      { #2 \__regex_compile_u_loop:NN }
      {
        \token_if_eq_meaning:NNTF #1 \__regex_compile_special:N
          {
            \exp_after:wN \token_if_eq_charcode:NNTF \c_right_brace_str #2
              { \if_false: { \fi: } \l__regex_internal_b_tl }
              {
```

```
        \if_charcode:w \c_left_brace_str #2
         \msg_expandable_error:nnn { regex } { cu-lbrace } { u }
        \else:
         #2
        \fi:
        \__regex_compile_u_loop:NN
       }
     }
     {
      \if_false: { \fi: }
      \msg_error:nne { regex } { u-missing-rbrace } {#2}
      \l__regex_internal_b_tl
      #1 #2
     }
   }
 }
```

(*__regex_compile_u_loop:NN* 定义结束。)

__regex_compile_ur_end:
__regex_compile_ur:n
__regex_compile_ur_aux:w

For the `\ur{...}` construction, once we have extracted the variable's name, we replace all groups by non-capturing groups in the compiled regex (passed as the argument of `\__regex_compile_ur:n`). If that has a single branch (namely `\tl_if_empty:oTF` is false) and there is no quantifier, then simply insert the contents of this branch (obtained by `\use_ii:nn`, which is expanded later). In all other cases, insert a non-capturing group and look for quantifiers to determine the number of repetition etc.

```
\cs_new_protected:Npn \__regex_compile_ur_end:
 {
  \group_begin:
   \cs_set:Npn \__regex_group:nnnN { \__regex_group_no_capture:nnnN }
   \cs_set:Npn \__regex_group_resetting:nnnN { \__regex_group_no_capture:nnnN }
   \exp_args:NNe
  \group_end:
  \__regex_compile_ur:n { \use:c { \l__regex_internal_a_tl } }
 }
\cs_new_protected:Npn \__regex_compile_ur:n #1
 {
  \tl_if_empty:oTF { \__regex_compile_ur_aux:w #1 {} ? ? \q__regex_nil }
   { \__regex_compile_if_quantifier:TFw }
   { \use_i:nn }
     {
      \tl_build_put_right:Nn \l__regex_build_tl
```

```
              { \__regex_group_no_capture:nnnN { \if_false: } \fi: #1 }
            \__regex_compile_quantifier:w
          }
          { \tl_build_put_right:Nn \l__regex_build_tl { \use_ii:nn #1 } }
  }
\cs_new:Npn \__regex_compile_ur_aux:w \__regex_branch:n #1#2#3 \q__regex_nil {#2}
```

(__regex_compile_ur_end:, __regex_compile_ur:n, 和 __regex_compile_ur_aux:w 定义结束。)

__regex_compile_u_end:
__regex_compile_u_payload:

Once we have extracted the variable's name, we check for quantifiers, in which case we set up a non-capturing group with a single branch. Inside this branch (we omit it and the group if there is no quantifier), __regex_compile_u_payload: puts the right tests corresponding to the contents of the variable, which we store in \l__regex_internal_a_tl. The behaviour of \u then depends on whether we are within a \c{...} escape (in this case, the variable is turned to a string), or not.

```
\cs_new_protected:Npn \__regex_compile_u_end:
  {
    \__regex_compile_if_quantifier:TFw
      {
        \tl_build_put_right:Nn \l__regex_build_tl
          {
            \__regex_group_no_capture:nnnN { \if_false: } \fi:
            \__regex_branch:n { \if_false: } \fi:
          }
        \__regex_compile_u_payload:
        \tl_build_put_right:Nn \l__regex_build_tl { \if_false: { \fi: } }
        \__regex_compile_quantifier:w
      }
      { \__regex_compile_u_payload: }
  }
\cs_new_protected:Npn \__regex_compile_u_payload:
  {
    \tl_set:Nv \l__regex_internal_a_tl { \l__regex_internal_a_tl }
    \if_int_compare:w \l__regex_mode_int = \c__regex_outer_mode_int
      \__regex_compile_u_not_cs:
    \else:
      \__regex_compile_u_in_cs:
    \fi:
  }
```

(__regex_compile_u_end: 和 __regex_compile_u_payload: 定义结束。)

__regex_compile_u_in_cs: When `\u` appears within a control sequence, we convert the variable to a string with escaped spaces. Then for each character insert a class matching exactly that character, once.

```
\cs_new_protected:Npn \__regex_compile_u_in_cs:
  {
    \__kernel_tl_gset:Ne \g__regex_internal_tl
      {
        \exp_args:No \__kernel_str_to_other_fast:n
          { \l__regex_internal_a_tl }
      }
    \tl_build_put_right:Ne \l__regex_build_tl
      {
        \tl_map_function:NN \g__regex_internal_tl
          \__regex_compile_u_in_cs_aux:n
      }
  }
\cs_new:Npn \__regex_compile_u_in_cs_aux:n #1
  {
    \__regex_class:NnnnN \c_true_bool
      { \__regex_item_caseful_equal:n { \int_value:w `#1 } }
      { 1 } { 0 } \c_false_bool
  }
```

(*__regex_compile_u_in_cs:* 定义结束。)

__regex_compile_u_not_cs: In mode 0, the `\u` escape adds one state to the NFA for each token in `\l__regex_internal_a_tl`. If a given ⟨*token*⟩ is a control sequence, then insert a string comparison test, otherwise, `\__regex_item_exact:nn` which compares catcode and character code.

```
\cs_new_protected:Npn \__regex_compile_u_not_cs:
  {
    \tl_analysis_map_inline:Nn \l__regex_internal_a_tl
      {
        \tl_build_put_right:Ne \l__regex_build_tl
          {
            \__regex_class:NnnnN \c_true_bool
              {
                \if_int_compare:w "##3 = \c_zero_int
                  \__regex_item_exact_cs:n
                    { \exp_after:wN \cs_to_str:N ##1 }
                \else:
                  \__regex_item_exact:nn { \int_value:w "##3 } { ##2 }
        \fi:
       }
       { 1 } { 0 } \c_false_bool
     }
   }
 }
```

(__regex_compile_u_not_cs: 定义结束。)

9.3.13 Other

__regex_compile_/K:

The \K control sequence is currently the only "command", which performs some action, rather than matching something. It is allowed in the same contexts as \b. At the compilation stage, we leave it as a single control sequence, defined later.

```
\cs_new_protected:cpn { __regex_compile_/K: }
 {
  \int_compare:nNnTF \l__regex_mode_int = \c__regex_outer_mode_int
   { \tl_build_put_right:Nn \l__regex_build_tl { \__regex_command_K: } }
   { \__regex_compile_raw_error:N K }
 }
```

(__regex_compile_/K: 定义结束。)

9.3.14 Showing regexes

__regex_clean_bool:n
__regex_clean_int:n
__regex_clean_int_aux:N
__regex_clean_regex:n
__regex_clean_regex_loop:w
__regex_clean_branch:n
__regex_clean_branch_loop:n
__regex_clean_assertion:Nn
__regex_clean_class:NnnnN
__regex_clean_group:nnnN
__regex_clean_class:n
__regex_clean_class_loop:nnn
__regex_clean_exact_cs:n
__regex_clean_exact_cs:w

Before showing a regex we check that it is "clean" in the sense that it has the correct internal structure. We do this (in the implementation of \regex_show:N and \regex_log:N) by comparing it with a cleaned-up version of the same regex. Along the way we also need similar functions for other types: all __regex_clean_⟨*type*⟩:n functions produce valid ⟨*type*⟩ tokens (bool, explicit integer, etc.) from arbitrary input, and the output coincides with the input if that was valid.

```
\cs_new:Npn \__regex_clean_bool:n #1
 {
  \tl_if_single:nTF {#1}
   { \bool_if:NTF #1 \c_true_bool \c_false_bool }
   { \c_true_bool }
 }
\cs_new:Npn \__regex_clean_int:n #1
 {
  \tl_if_head_eq_meaning:nNTF {#1} -
   { - \exp_args:No \__regex_clean_int:n { \use_none:n #1 } }
   { \int_eval:n { 0 \str_map_function:nN {#1} \__regex_clean_int_aux:N } }
  }
\cs_new:Npn \__regex_clean_int_aux:N #1
  {
    \if_int_compare:w 1 < 1 #1 ~
      #1
    \else:
      \exp_after:wN \str_map_break:
    \fi:
  }
\cs_new:Npn \__regex_clean_regex:n #1
  {
    \__regex_clean_regex_loop:w #1
    \__regex_branch:n { \q_recursion_tail } \q_recursion_stop
  }
\cs_new:Npn \__regex_clean_regex_loop:w #1 \__regex_branch:n #2
  {
    \quark_if_recursion_tail_stop:n {#2}
    \__regex_branch:n { \__regex_clean_branch:n {#2} }
    \__regex_clean_regex_loop:w
  }
\cs_new:Npn \__regex_clean_branch:n #1
  {
    \__regex_clean_branch_loop:n #1
    ? ? ? ? ? ? \prg_break_point:
  }
\cs_new:Npn \__regex_clean_branch_loop:n #1
  {
    \tl_if_single:nF {#1} { \prg_break: }
    \token_case_meaning:NnF #1
      {
        \__regex_command_K: { #1 \__regex_clean_branch_loop:n }
        \__regex_assertion:Nn { #1 \__regex_clean_assertion:Nn }
        \__regex_class:NnnnN { #1 \__regex_clean_class:NnnnN }
        \__regex_group:nnnN { #1 \__regex_clean_group:nnnN }
        \__regex_group_no_capture:nnnN { #1 \__regex_clean_group:nnnN }
        \__regex_group_resetting:nnnN { #1 \__regex_clean_group:nnnN }
      }
      { \prg_break: }
  }
\cs_new:Npn \__regex_clean_assertion:Nn #1#2
  {
    \__regex_clean_bool:n {#1}
    \tl_if_single:nF {#2} { { \__regex_A_test: } \prg_break: }
    \token_case_meaning:NnTF #2
      {
        \__regex_A_test: { }
        \__regex_G_test: { }
        \__regex_Z_test: { }
        \__regex_b_test: { }
      }
      { {#2} }
      { { \__regex_A_test: } \prg_break: }
    \__regex_clean_branch_loop:n
  }
\cs_new:Npn \__regex_clean_class:NnnnN #1#2#3#4#5
  {
    \__regex_clean_bool:n {#1}
    { \__regex_clean_class:n {#2} }
    { \int_max:nn { 0 } { \__regex_clean_int:n {#3} } }
    { \int_max:nn { -1 } { \__regex_clean_int:n {#4} } }
    \__regex_clean_bool:n {#5}
    \__regex_clean_branch_loop:n
  }
\cs_new:Npn \__regex_clean_group:nnnN #1#2#3#4
  {
    { \__regex_clean_regex:n {#1} }
    { \int_max:nn { 0 } { \__regex_clean_int:n {#2} } }
    { \int_max:nn { -1 } { \__regex_clean_int:n {#3} } }
    \__regex_clean_bool:n {#4}
    \__regex_clean_branch_loop:n
  }
\cs_new:Npn \__regex_clean_class:n #1
  { \__regex_clean_class_loop:nnn #1 ????? \prg_break_point: }
```

When cleaning a class there are many cases, including a dozen or so like `\__regex_prop_d:` or `\__regex_posix_alpha:`. To avoid listing all of them we allow any command that starts with the 13 characters `__regex_prop_` or `__regex_posix` (handily these have the same length, except for the trailing underscore).

```
\cs_new:Npn \__regex_clean_class_loop:nnn #1#2#3
  {
    \tl_if_single:nF {#1} { \prg_break: }
    \token_case_meaning:NnTF #1
      {
        \__regex_item_cs:n { #1 { \__regex_clean_regex:n {#2} } }
        \__regex_item_exact_cs:n { #1 { \__regex_clean_exact_cs:n {#2} } }
        \__regex_item_caseful_equal:n { #1 { \__regex_clean_int:n {#2} } }
        \__regex_item_caseless_equal:n { #1 { \__regex_clean_int:n {#2} } }
        \__regex_item_reverse:n { #1 { \__regex_clean_class:n {#2} } }
      }
      { \__regex_clean_class_loop:nnn {#3} }
      {
        \token_case_meaning:NnTF #1
          {
            \__regex_item_caseful_range:nn { }
            \__regex_item_caseless_range:nn { }
            \__regex_item_exact:nn { }
          }
          {
            #1 { \__regex_clean_int:n {#2} } { \__regex_clean_int:n {#3} }
            \__regex_clean_class_loop:nnn
          }
          {
            \token_case_meaning:NnTF #1
              {
                \__regex_item_catcode:nT { }
                \__regex_item_catcode_reverse:nT { }
              }
              {
                #1 { \__regex_clean_int:n {#2} } { \__regex_clean_class:n {#3} }
                \__regex_clean_class_loop:nnn
              }
              {
                \exp_args:Nf \str_case:nnTF
                  {
                    \exp_args:Nf \str_range:nnn
                      { \cs_to_str:N #1 } { 1 } { 13 }
                  }
                  {
                    { __regex_prop_ } { }
                    { __regex_posix } { }
                  }
                  {
                    #1
                    \__regex_clean_class_loop:nnn {#2} {#3}
                  }
                  { \prg_break: }
```

```
       }
     }
   }
 }
\cs_new:Npn \__regex_clean_exact_cs:n #1
 {
  \exp_last_unbraced:Nf \use_none:n
   {
    \__regex_clean_exact_cs:w #1
    \scan_stop: \q_recursion_tail \scan_stop:
    \q_recursion_stop
   }
 }
\cs_new:Npn \__regex_clean_exact_cs:w #1 \scan_stop:
 {
  \quark_if_recursion_tail_stop:n {#1}
  \scan_stop: \tl_to_str:n {#1}
  \__regex_clean_exact_cs:w
 }
```

(*__regex_clean_bool:n 以及其它的定义结束。*)

__regex_show:N

Within a group and within \tl_build_begin:N … \tl_build_end:N we redefine all the function that can appear in a compiled regex, then run the regex. The result stored in \l__regex_internal_a_tl is then meant to be shown.

```
\cs_new_protected:Npn \__regex_show:N #1
 {
  \group_begin:
   \tl_build_begin:N \l__regex_build_tl
   \cs_set_protected:Npn \__regex_branch:n
    {
     \seq_pop_right:NN \l__regex_show_prefix_seq
      \l__regex_internal_a_tl
     \__regex_show_one:n { +-branch }
     \seq_put_right:No \l__regex_show_prefix_seq
      \l__regex_internal_a_tl
     \use:n
    }
   \cs_set_protected:Npn \__regex_group:nnnN
    { \__regex_show_group_aux:nnnnN { } }
   \cs_set_protected:Npn \__regex_group_no_capture:nnnN
    { \__regex_show_group_aux:nnnnN { ~(no~capture) } }
    \cs_set_protected:Npn \__regex_group_resetting:nnnN
      { \__regex_show_group_aux:nnnnN { ~(resetting) } }
    \cs_set_eq:NN \__regex_class:NnnnN \__regex_show_class:NnnnN
    \cs_set_protected:Npn \__regex_command_K:
      { \__regex_show_one:n { reset~match~start~(\iow_char:N\\K) } }
    \cs_set_protected:Npn \__regex_assertion:Nn ##1##2
      {
        \__regex_show_one:n
          { \bool_if:NF ##1 { negative~ } assertion:~##2 }
      }
    \cs_set:Npn \__regex_b_test: { word~boundary }
    \cs_set:Npn \__regex_Z_test: { anchor~at~end~(\iow_char:N\\Z) }
    \cs_set:Npn \__regex_A_test: { anchor~at~start~(\iow_char:N\\A) }
    \cs_set:Npn \__regex_G_test: { anchor~at~start~of~match~(\iow_char:N\\G) }
    \cs_set_protected:Npn \__regex_item_caseful_equal:n ##1
      { \__regex_show_one:n { char~code~\__regex_show_char:n{##1} } }
    \cs_set_protected:Npn \__regex_item_caseful_range:nn ##1##2
      {
        \__regex_show_one:n
          { range~[\__regex_show_char:n{##1}, \__regex_show_char:n{##2}] }
      }
    \cs_set_protected:Npn \__regex_item_caseless_equal:n ##1
      { \__regex_show_one:n { char~code~\__regex_show_char:n{##1}~(caseless) } }
    \cs_set_protected:Npn \__regex_item_caseless_range:nn ##1##2
      {
        \__regex_show_one:n
          { Range~[\__regex_show_char:n{##1}, \__regex_show_char:n{##2}]~(caseless) }
      }
    \cs_set_protected:Npn \__regex_item_catcode:nT
      { \__regex_show_item_catcode:NnT \c_true_bool }
    \cs_set_protected:Npn \__regex_item_catcode_reverse:nT
      { \__regex_show_item_catcode:NnT \c_false_bool }
    \cs_set_protected:Npn \__regex_item_reverse:n
      { \__regex_show_scope:nn { Reversed~match } }
    \cs_set_protected:Npn \__regex_item_exact:nn ##1##2
      { \__regex_show_one:n { char~\__regex_show_char:n{##2},~catcode~##1 } }
    \cs_set_eq:NN \__regex_item_exact_cs:n \__regex_show_item_exact_cs:n
    \cs_set_protected:Npn \__regex_item_cs:n
      { \__regex_show_scope:nn { control~sequence } }
    \cs_set:cpn { __regex_prop_.: } { \__regex_show_one:n { any~token } }
    \seq_clear:N \l__regex_show_prefix_seq
    \__regex_show_push:n { ~ }
```

```
      \cs_if_exist_use:N #1
      \tl_build_end:N \l__regex_build_tl
      \exp_args:NNNo
    \group_end:
    \tl_set:Nn \l__regex_internal_a_tl { \l__regex_build_tl }
  }
```

(__*regex_show:N* 定义结束。)

__regex_show_char:n

Show a single character, together with its ascii representation if available. This could be extended to beyond ascii. It is not ideal for parentheses themselves.

```
\cs_new:Npn \__regex_show_char:n #1
  {
    \int_eval:n {#1}
    \int_compare:nT { 32 <= #1 <= 126 }
      { ~ ( \char_generate:nn {#1} {12} ) }
  }
```

(__*regex_show_char:n* 定义结束。)

__regex_show_one:n

Every part of the final message go through this function, which adds one line to the output, with the appropriate prefix.

```
\cs_new_protected:Npn \__regex_show_one:n #1
  {
    \int_incr:N \l__regex_show_lines_int
    \tl_build_put_right:Ne \l__regex_build_tl
      {
        \exp_not:N \iow_newline:
        \seq_map_function:NN \l__regex_show_prefix_seq \use:n
        #1
      }
  }
```

(__*regex_show_one:n* 定义结束。)

__regex_show_push:n
__regex_show_pop:
__regex_show_scope:nn

Enter and exit levels of nesting. The `scope` function prints its first argument as an “introduction”, then performs its second argument in a deeper level of nesting.

```
\cs_new_protected:Npn \__regex_show_push:n #1
  { \seq_put_right:Ne \l__regex_show_prefix_seq { #1 ~ } }
\cs_new_protected:Npn \__regex_show_pop:
  { \seq_pop_right:NN \l__regex_show_prefix_seq \l__regex_internal_a_tl }
\cs_new_protected:Npn \__regex_show_scope:nn #1#2
  {
    \__regex_show_one:n {#1}
    \__regex_show_push:n { ~ }
    #2
    \__regex_show_pop:
  }
```

(__*regex_show_push:n*, __*regex_show_pop:*, 和 __*regex_show_scope:nn* 定义结束。)

__regex_show_group_aux:nnnnN

We display all groups in the same way, simply adding a message, `(no capture)` or `(resetting)`, to special groups. The odd `\use_ii:nn` avoids printing a spurious `+-branch` for the first branch.

```
\cs_new_protected:Npn \__regex_show_group_aux:nnnnN #1#2#3#4#5
  {
    \__regex_show_one:n { ,-group~begin #1 }
    \__regex_show_push:n { | }
    \use_ii:nn #2
    \__regex_show_pop:
    \__regex_show_one:n
      { `-group~end \__regex_msg_repeated:nnN {#3} {#4} #5 }
  }
```

(__*regex_show_group_aux:nnnnN* 定义结束。)

__regex_show_class:NnnnN

I'm entirely unhappy about this function: I couldn't find a way to test if a class is a single test. Instead, collect the representation of the tests in the class. If that had more than one line, write `Match` or `Don't match` on its own line, with the repeating information if any. Then the various tests on lines of their own, and finally a line. Otherwise, we need to evaluate the representation of the tests again (since the prefix is incorrect). That's clunky, but not too expensive, since it's only one test.

```
\cs_set:Npn \__regex_show_class:NnnnN #1#2#3#4#5
  {
    \group_begin:
      \tl_build_begin:N \l__regex_build_tl
      \int_zero:N \l__regex_show_lines_int
      \__regex_show_push:n {~}
      #2
    \int_compare:nTF { \l__regex_show_lines_int = 0 }
      {
        \group_end:
        \__regex_show_one:n { \bool_if:NTF #1 { Fail } { Pass } }
      }
      {
        \bool_if:nTF
          { #1 && \int_compare_p:n { \l__regex_show_lines_int = 1 } }
          {
            \group_end:
            #2
            \tl_build_put_right:Nn \l__regex_build_tl
              { \__regex_msg_repeated:nnN {#3} {#4} #5 }
          }
          {
              \tl_build_end:N \l__regex_build_tl
              \exp_args:NNNo
            \group_end:
            \tl_set:Nn \l__regex_internal_a_tl \l__regex_build_tl
            \__regex_show_one:n
              {
                \bool_if:NTF #1 { Match } { Don't~match }
                \__regex_msg_repeated:nnN {#3} {#4} #5
              }
            \tl_build_put_right:Ne \l__regex_build_tl
              { \exp_not:o \l__regex_internal_a_tl }
          }
      }
  }
```

(*__regex_show_class:NnnnN* 定义结束。)

__regex_show_item_catcode:NnT

Produce a sequence of categories which the catcode bitmap #2 contains, and show it, indenting the tests on which this catcode constraint applies.

```
\cs_new_protected:Npn \__regex_show_item_catcode:NnT #1#2
  {
    \seq_set_split:Nnn \l__regex_internal_seq { } { CBEMTPUDSLOA }
    \seq_set_filter:NNn \l__regex_internal_seq \l__regex_internal_seq
      { \int_if_odd_p:n { #2 / \int_use:c { c__regex_catcode_##1_int } } }
    \__regex_show_scope:nn
      {
        categories~
        \seq_map_function:NN \l__regex_internal_seq \use:n
        , ~
        \bool_if:NF #1 { negative~ } class
      }
  }
```

(*__regex_show_item_catcode:NnT* 定义结束。)

__regex_show_item_exact_cs:n

```
\cs_new_protected:Npn \__regex_show_item_exact_cs:n #1
  {
    \seq_set_split:Nnn \l__regex_internal_seq { \scan_stop: } {#1}
    \seq_set_map_e:NNn \l__regex_internal_seq
      \l__regex_internal_seq { \iow_char:N\\##1 }
    \__regex_show_one:n
      { control~sequence~ \seq_use:Nn \l__regex_internal_seq { ~or~ } }
  }
```

(__*regex_show_item_exact_cs:n* 定义结束。)

9.4 Building

9.4.1 Variables used while building

\l__regex_min_state_int
\l__regex_max_state_int

The last state that was allocated is \l__regex_max_state_int − 1, so that \l__regex_max_state_int always points to a free state. The min_state variable is 1 to begin with, but gets shifted in nested calls to the matching code, namely in \c{...} constructions.

```
\int_new:N  \l__regex_min_state_int
\int_set:Nn \l__regex_min_state_int { 1 }
\int_new:N  \l__regex_max_state_int
```

(*\l__regex_min_state_int* 和 *\l__regex_max_state_int* 定义结束。)

\l__regex_left_state_int
\l__regex_right_state_int
\l__regex_left_state_seq
\l__regex_right_state_seq

Alternatives are implemented by branching from a left state into the various choices, then merging those into a right state. We store information about those states in two sequences. Those states are also used to implement group quantifiers. Most often, the left and right pointers only differ by 1.

```
\int_new:N  \l__regex_left_state_int
\int_new:N  \l__regex_right_state_int
\seq_new:N  \l__regex_left_state_seq
\seq_new:N  \l__regex_right_state_seq
```

(*\l__regex_left_state_int* 以及其它的定义结束。)

\l__regex_capturing_group_int

\l__regex_capturing_group_int is the next ID number to be assigned to a capturing group. This starts at 0 for the group enclosing the full regular expression, and groups are counted in the order of their left parenthesis, except when encountering resetting groups.

```
\int_new:N  \l__regex_capturing_group_int
```

(*\l__regex_capturing_group_int* 定义结束。)

9.4.2 Framework

This phase is about going from a compiled regex to an NFA. Each state of the NFA is stored in a `\toks`. The operations which can appear in the `\toks` are

- `\__regex_action_start_wildcard:N` ⟨*boolean*⟩ inserted at the start of the regular expression, where a `true` ⟨*boolean*⟩ makes it unanchored.
- `\__regex_action_success:` marks the exit state of the NFA.
- `\__regex_action_cost:n {`⟨*shift*⟩`}` is a transition from the current ⟨*state*⟩ to ⟨*state*⟩ + ⟨*shift*⟩, which consumes the current character: the target state is saved and will be considered again when matching at the next position.
- `\__regex_action_free:n {`⟨*shift*⟩`}`, and `\__regex_action_free_group:n {`⟨*shift*⟩`}` are free transitions, which immediately perform the actions for the state ⟨*state*⟩ + ⟨*shift*⟩ of the NFA. They differ in how they detect and avoid infinite loops. For now, we just need to know that the `group` variant must be used for transitions back to the start of a group.
- `\__regex_action_submatch:nN {`⟨*group*⟩`}` ⟨*key*⟩ where the ⟨*key*⟩ is `<` or `>` for the beginning or end of group numbered ⟨*group*⟩. This causes the current position in the query to be stored as the ⟨*key*⟩ submatch boundary.
- One of these actions, within a conditional.

We strive to preserve the following properties while building.

- The current capturing group is `capturing_group` − 1, and if a group opened now it would be labelled `capturing_group`.
- The last allocated state is `max_state` − 1, so `max_state` is a free state.
- The `left_state` points to a state to the left of the current group or of the last class.
- The `right_state` points to a newly created, empty state, with some transitions leading to it.
- The `left/right` sequences hold a list of the corresponding end-points of nested groups.

__regex_build:n
__regex_build_aux:Nn
__regex_build:N
__regex_build_aux:NN

The n-type function first compiles its argument. Reset some variables. Allocate two states, and put a wildcard in state 0 (transitions to state 1 and 0 state). Then build the regex within a (capturing) group numbered 0 (current value of capturing_group). Finally, if the match reaches the last state, it is successful. A false boolean for argument #1 for the auxiliaries will suppress the wildcard and make the match anchored: used for \peek_regex:nTF and similar.

```
\cs_new_protected:Npn \__regex_build:n
  { \__regex_build_aux:Nn \c_true_bool }
\cs_new_protected:Npn \__regex_build:N
  { \__regex_build_aux:NN \c_true_bool }
\cs_new_protected:Npn \__regex_build_aux:Nn #1#2
  {
    \__regex_compile:n {#2}
    \__regex_build_aux:NN #1 \l__regex_internal_regex
  }
\cs_new_protected:Npn \__regex_build_aux:NN #1#2
  {
    \__regex_standard_escapechar:
    \int_zero:N \l__regex_capturing_group_int
    \int_set_eq:NN \l__regex_max_state_int \l__regex_min_state_int
    \__regex_build_new_state:
    \__regex_build_new_state:
    \__regex_toks_put_right:Nn \l__regex_left_state_int
      { \__regex_action_start_wildcard:N #1 }
    \__regex_group:nnnN {#2} { 1 } { 0 } \c_false_bool
    \__regex_toks_put_right:Nn \l__regex_right_state_int
      { \__regex_action_success: }
  }
```

(*__regex_build:n* 以及其它的定义结束。)

\g__regex_case_int

Case number that was successfully matched in \regex_match_case:nn and related functions.

```
\int_new:N \g__regex_case_int
```

(*\g__regex_case_int* 定义结束。)

\l__regex_case_max_group_int

The largest group number appearing in any of the ⟨*regex*⟩ in the argument of \regex_match_case:nn and related functions.

```
\int_new:N \l__regex_case_max_group_int
```

(*\l__regex_case_max_group_int* 定义结束。)

__regex_case_build:n
__regex_case_build:e
__regex_case_build_aux:Nn
__regex_case_build_loop:n

See `\__regex_build:n`, but with a loop.

```
\cs_new_protected:Npn \__regex_case_build:n #1
  {
    \__regex_case_build_aux:Nn \c_true_bool {#1}
    \int_gzero:N \g__regex_case_int
  }
\cs_generate_variant:Nn \__regex_case_build:n { e }
\cs_new_protected:Npn \__regex_case_build_aux:Nn #1#2
  {
    \__regex_standard_escapechar:
    \int_set_eq:NN \l__regex_max_state_int \l__regex_min_state_int
    \__regex_build_new_state:
    \__regex_build_new_state:
    \__regex_toks_put_right:Nn \l__regex_left_state_int
      { \__regex_action_start_wildcard:N #1 }
    %
    \__regex_build_new_state:
    \__regex_toks_put_left:Ne \l__regex_left_state_int
      { \__regex_action_submatch:nN { 0 } < }
    \__regex_push_lr_states:
    \int_zero:N \l__regex_case_max_group_int
    \int_gzero:N \g__regex_case_int
    \tl_map_inline:nn {#2}
      {
        \int_gincr:N \g__regex_case_int
        \__regex_case_build_loop:n {##1}
      }
    \int_set_eq:NN \l__regex_capturing_group_int \l__regex_case_max_group_int
    \__regex_pop_lr_states:
  }
\cs_new_protected:Npn \__regex_case_build_loop:n #1
  {
    \int_set:Nn \l__regex_capturing_group_int { 1 }
    \__regex_compile_use:n {#1}
    \int_set:Nn \l__regex_case_max_group_int
      {
        \int_max:nn { \l__regex_case_max_group_int }
          { \l__regex_capturing_group_int }
      }
    \seq_pop:NN \l__regex_right_state_seq \l__regex_internal_a_tl
    \int_set:Nn \l__regex_right_state_int \l__regex_internal_a_tl
    \__regex_toks_put_left:Ne \l__regex_right_state_int
```

```
      {
        \__regex_action_submatch:nN { 0 } >
        \int_gset:Nn \g__regex_case_int
          { \int_use:N \g__regex_case_int }
        \__regex_action_success:
      }
    \__regex_toks_clear:N \l__regex_max_state_int
    \seq_push:No \l__regex_right_state_seq
      { \int_use:N \l__regex_max_state_int }
    \int_incr:N \l__regex_max_state_int
  }
```

（*__regex_case_build:n*，*__regex_case_build_aux:Nn*，和 *__regex_case_build_loop:n* 定义结束。）

__regex_build_for_cs:n

The matching code relies on some global intarray variables, but only uses a range of their entries. Specifically,

- \g__regex_state_active_intarray from \l__regex_min_state_int to \l__regex_max_st
  1;

Here, in this nested call to the matching code, we need the new versions of this range to involve completely new entries of the intarray variables, so we begin by setting (the new) \l__regex_min_state_int to (the old) \l__regex_max_state_int to use higher entries.

When using a regex to match a cs, we don't insert a wildcard, we anchor at the end, and since we ignore submatches, there is no need to surround the expression with a group. However, for branches to work properly at the outer level, we need to put the appropriate left and right states in their sequence.

```
\cs_new_protected:Npn \__regex_build_for_cs:n #1
  {
    \int_set_eq:NN \l__regex_min_state_int \l__regex_max_state_int
    \__regex_build_new_state:
    \__regex_build_new_state:
    \__regex_push_lr_states:
    #1
    \__regex_pop_lr_states:
    \__regex_toks_put_right:Nn \l__regex_right_state_int
      {
        \if_int_compare:w -2 = \l__regex_curr_char_int
          \exp_after:wN \__regex_action_success:
        \fi:
      }
  }
```

(*__regex_build_for_cs:n* 定义结束。)

9.4.3 Helpers for building an nfa

`\__regex_push_lr_states:`
`\__regex_pop_lr_states:`

When building the regular expression, we keep track of pointers to the left-end and right-end of each group without help from TEX's grouping.

```
\cs_new_protected:Npn \__regex_push_lr_states:
  {
    \seq_push:No \l__regex_left_state_seq
      { \int_use:N \l__regex_left_state_int }
    \seq_push:No \l__regex_right_state_seq
      { \int_use:N \l__regex_right_state_int }
  }
\cs_new_protected:Npn \__regex_pop_lr_states:
  {
    \seq_pop:NN \l__regex_left_state_seq  \l__regex_internal_a_tl
    \int_set:Nn \l__regex_left_state_int  \l__regex_internal_a_tl
    \seq_pop:NN \l__regex_right_state_seq \l__regex_internal_a_tl
    \int_set:Nn \l__regex_right_state_int \l__regex_internal_a_tl
  }
```

(*__regex_push_lr_states:* 和 *__regex_pop_lr_states:* 定义结束。)

`\__regex_build_transition_left:NNN`
`\__regex_build_transition_right:nNn`

Add a transition from `#2` to `#3` using the function `#1`. The `left` function is used for higher priority transitions, and the `right` function for lower priority transitions (which should be performed later). The signatures differ to reflect the differing usage later on. Both functions could be optimized.

```
\cs_new_protected:Npn \__regex_build_transition_left:NNN #1#2#3
  { \__regex_toks_put_left:Ne  #2 { #1 { \int_eval:n { #3 - #2 } } } }
\cs_new_protected:Npn \__regex_build_transition_right:nNn #1#2#3
  { \__regex_toks_put_right:Ne #2 { #1 { \int_eval:n { #3 - #2 } } } }
```

(*__regex_build_transition_left:NNN* 和 *__regex_build_transition_right:nNn* 定义结束。)

`\__regex_build_new_state:`

Add a new empty state to the NFA. Then update the `left`, `right`, and `max` states, so that the `right` state is the new empty state, and the `left` state points to the previously "current" state.

```
\cs_new_protected:Npn \__regex_build_new_state:
  {
    \__regex_toks_clear:N \l__regex_max_state_int
    \int_set_eq:NN \l__regex_left_state_int \l__regex_right_state_int
    \int_set_eq:NN \l__regex_right_state_int \l__regex_max_state_int
    \int_incr:N \l__regex_max_state_int
  }
```

(*__regex_build_new_state:* 定义结束。)

__regex_build_transitions_lazyness:NNNNN

This function creates a new state, and puts two transitions starting from the old current state. The order of the transitions is controlled by `#1`, true for lazy quantifiers, and false for greedy quantifiers.

```
\cs_new_protected:Npn \__regex_build_transitions_lazyness:NNNNN #1#2#3#4#5
  {
    \__regex_build_new_state:
    \__regex_toks_put_right:Ne \l__regex_left_state_int
      {
        \if_meaning:w \c_true_bool #1
          #2 { \int_eval:n { #3 - \l__regex_left_state_int } }
          #4 { \int_eval:n { #5 - \l__regex_left_state_int } }
        \else:
          #4 { \int_eval:n { #5 - \l__regex_left_state_int } }
          #2 { \int_eval:n { #3 - \l__regex_left_state_int } }
        \fi:
      }
  }
```

(*__regex_build_transitions_lazyness:NNNNN* 定义结束。)

9.4.4 Building classes

__regex_class:NnnnN
__regex_tests_action_cost:n

The arguments are: ⟨*boolean*⟩ `{`⟨*tests*⟩`}` `{`⟨*min*⟩`}` `{`⟨*more*⟩`}` ⟨*lazyness*⟩. First store the tests with a trailing `\__regex_action_cost:n`, in the true branch of `\__regex_break_point:TF` for positive classes, or the false branch for negative classes. The integer ⟨*more*⟩ is 0 for fixed repetitions, −1 for unbounded repetitions, and ⟨*max*⟩ − ⟨*min*⟩ for a range of repetitions.

```
\cs_new_protected:Npn \__regex_class:NnnnN #1#2#3#4#5
  {
    \cs_set:Npe \__regex_tests_action_cost:n ##1
      {
        \exp_not:n { \exp_not:n {#2} }
        \bool_if:NTF #1
          { \__regex_break_point:TF { \__regex_action_cost:n {##1} } { } }
          { \__regex_break_point:TF { } { \__regex_action_cost:n {##1} } }
      }
    \if_case:w - #4 \exp_stop_f:
           \__regex_class_repeat:n   {#3}
    \or:   \__regex_class_repeat:nN  {#3}      #5
    \else: \__regex_class_repeat:nnN {#3} {#4} #5
    \fi:
  }
\cs_new:Npn \__regex_tests_action_cost:n { \__regex_action_cost:n }
```

(*__regex_class:NnnnN* 和 *__regex_tests_action_cost:n* 定义结束。)

__regex_class_repeat:n This is used for a fixed number of repetitions. Build one state for each repetition, with a transition controlled by the tests that we have collected. That works just fine for #1 $= 0$ repetitions: nothing is built.

```
\cs_new_protected:Npn \__regex_class_repeat:n #1
  {
    \prg_replicate:nn {#1}
      {
        \__regex_build_new_state:
        \__regex_build_transition_right:nNn \__regex_tests_action_cost:n
          \l__regex_left_state_int \l__regex_right_state_int
      }
  }
```

(*__regex_class_repeat:n* 定义结束。)

__regex_class_repeat:nN This implements unbounded repetitions of a single class (*e.g.* the * and + quantifiers). If the minimum number #1 of repetitions is 0, then build a transition from the current state to itself governed by the tests, and a free transition to a new state (hence skipping the tests). Otherwise, call **__regex_class_repeat:n** for the code to match #1 repetitions, and add free transitions from the last state to the previous one, and to a new one. In both cases, the order of transitions is controlled by the lazyness boolean #2.

```
\cs_new_protected:Npn \__regex_class_repeat:nN #1#2
  {
    \if_int_compare:w #1 = \c_zero_int
      \__regex_build_transitions_lazyness:NNNNN #2
        \__regex_action_free:n       \l__regex_right_state_int
        \__regex_tests_action_cost:n \l__regex_left_state_int
    \else:
      \__regex_class_repeat:n {#1}
      \int_set_eq:NN \l__regex_internal_a_int \l__regex_left_state_int
      \__regex_build_transitions_lazyness:NNNNN #2
        \__regex_action_free:n \l__regex_right_state_int
        \__regex_action_free:n \l__regex_internal_a_int
    \fi:
  }
```

（*__regex_class_repeat:nN* 定义结束。）

__regex_class_repeat:nnN We want to build the code to match from #1 to #1 + #2 repetitions. Match #1 repetitions (can be 0). Compute the final state of the next construction as a. Build #2 > 0 states, each with a transition to the next state governed by the tests, and a transition to the final state a. The computation of a is safe because states are allocated in order, starting from max_state.

```
\cs_new_protected:Npn \__regex_class_repeat:nnN #1#2#3
  {
    \__regex_class_repeat:n {#1}
    \int_set:Nn \l__regex_internal_a_int
      { \l__regex_max_state_int + #2 - 1 }
    \prg_replicate:nn { #2 }
      {
        \__regex_build_transitions_lazyness:NNNNN #3
          \__regex_action_free:n       \l__regex_internal_a_int
          \__regex_tests_action_cost:n \l__regex_right_state_int
      }
  }
```

（*__regex_class_repeat:nnN* 定义结束。）

9.4.5 Building groups

__regex_group_aux:nnnnN Arguments: {⟨*label*⟩} {⟨*contents*⟩} {⟨*min*⟩} {⟨*more*⟩} ⟨*lazyness*⟩. If ⟨*min*⟩ is 0, we need to add a state before building the group, so that the thread which skips the group does not also set the start-point of the submatch. After adding one more state, the left_state is the left end of the group, from which all branches stem, and the right_state is the right end of the group, and all branches end their course in that state. We store those two integers to be queried for each branch, we build the NFA states for the contents #2 of the group, and we forget about the two integers. Once this is done, perform the repetition: either exactly #3 times, or #3 or more times, or between #3 and #3 + #4 times, with lazyness #5. The ⟨*label*⟩ #1 is used for submatch tracking. Each of the three auxiliaries expects left_state and right_state to be set properly.

```
\cs_new_protected:Npn \__regex_group_aux:nnnnN #1#2#3#4#5
  {
      \if_int_compare:w #3 = \c_zero_int
        \__regex_build_new_state:
        \__regex_build_transition_right:nNn \__regex_action_free_group:n
          \l__regex_left_state_int \l__regex_right_state_int
      \fi:
      \__regex_build_new_state:
      \__regex_push_lr_states:
      #2
      \__regex_pop_lr_states:
      \if_case:w - #4 \exp_stop_f:
             \__regex_group_repeat:nn   {#1} {#3}
      \or:   \__regex_group_repeat:nnN  {#1} {#3}      #5
      \else: \__regex_group_repeat:nnnN {#1} {#3} {#4} #5
      \fi:
  }
```

(*__regex_group_aux:nnnnN* 定义结束。)

__regex_group:nnnN
__regex_group_no_capture:nnnN

Hand to __regex_group_aux:nnnnnN the label of that group (expanded), and the group itself, with some extra commands to perform.

```
\cs_new_protected:Npn \__regex_group:nnnN #1
  {
    \exp_args:No \__regex_group_aux:nnnnN
      { \int_use:N \l__regex_capturing_group_int }
      {
        \int_incr:N \l__regex_capturing_group_int
        #1
      }
  }
\cs_new_protected:Npn \__regex_group_no_capture:nnnN
  { \__regex_group_aux:nnnnN { -1 } }
```

(*__regex_group:nnnN* 和 *__regex_group_no_capture:nnnN* 定义结束。)

__regex_group_resetting:nnnN
__regex_group_resetting_loop:nnNn

Again, hand the label −1 to __regex_group_aux:nnnnN, but this time we work a little bit harder to keep track of the maximum group label at the end of any branch, and to reset the group number at each branch. This relies on the fact that a compiled regex always is a sequence of items of the form __regex_branch:n {⟨*branch*⟩}.

```
\cs_new_protected:Npn \__regex_group_resetting:nnnN #1
  {
    \__regex_group_aux:nnnnN { -1 }
      {
        \exp_args:Noo \__regex_group_resetting_loop:nnNn
          { \int_use:N \l__regex_capturing_group_int }
          { \int_use:N \l__regex_capturing_group_int }
          #1
          { ?? \prg_break:n } { }
        \prg_break_point:
      }
  }
\cs_new_protected:Npn \__regex_group_resetting_loop:nnNn #1#2#3#4
  {
    \use_none:nn #3 { \int_set:Nn \l__regex_capturing_group_int {#1} }
    \int_set:Nn \l__regex_capturing_group_int {#2}
    #3 {#4}
    \exp_args:Nf \__regex_group_resetting_loop:nnNn
      { \int_max:nn {#1} { \l__regex_capturing_group_int } }
      {#2}
  }
```

（*__regex_group_resetting:nnnN* 和 *__regex_group_resetting_loop:nnNn* 定义结束。）

__regex_branch:n Add a free transition from the left state of the current group to a brand new state, starting point of this branch. Once the branch is built, add a transition from its last state to the right state of the group. The left and right states of the group are extracted from the relevant sequences.

```
\cs_new_protected:Npn \__regex_branch:n #1
  {
    \__regex_build_new_state:
    \seq_get:NN \l__regex_left_state_seq \l__regex_internal_a_tl
    \int_set:Nn \l__regex_left_state_int \l__regex_internal_a_tl
    \__regex_build_transition_right:nNn \__regex_action_free:n
      \l__regex_left_state_int \l__regex_right_state_int
    #1
    \seq_get:NN \l__regex_right_state_seq \l__regex_internal_a_tl
    \__regex_build_transition_right:nNn \__regex_action_free:n
      \l__regex_right_state_int \l__regex_internal_a_tl
  }
```

（*__regex_branch:n* 定义结束。）

__regex_group_repeat:nn This function is called to repeat a group a fixed number of times `#2`; if this is 0 we remove the group altogether (but don't reset the `capturing_group` label).

Otherwise, the auxiliary __regex_group_repeat_aux:n copies #2 times the \toks for the group, and leaves internal_a pointing to the left end of the last repetition. We only record the submatch information at the last repetition. Finally, add a state at the end (the transition to it has been taken care of by the replicating auxiliary).

```
\cs_new_protected:Npn \__regex_group_repeat:nn #1#2
  {
    \if_int_compare:w #2 = \c_zero_int
      \int_set:Nn \l__regex_max_state_int
        { \l__regex_left_state_int - 1 }
      \__regex_build_new_state:
    \else:
      \__regex_group_repeat_aux:n {#2}
      \__regex_group_submatches:nNN {#1}
        \l__regex_internal_a_int \l__regex_right_state_int
      \__regex_build_new_state:
    \fi:
  }
```

(*__regex_group_repeat:nn* 定义结束。)

__regex_group_submatches:nNN

This inserts in states #2 and #3 the code for tracking submatches of the group #1, unless inhibited by a label of -1.

```
\cs_new_protected:Npn \__regex_group_submatches:nNN #1#2#3
  {
    \if_int_compare:w #1 > - \c_one_int
      \__regex_toks_put_left:Ne #2 { \__regex_action_submatch:nN {#1} < }
      \__regex_toks_put_left:Ne #3 { \__regex_action_submatch:nN {#1} > }
    \fi:
  }
```

(*__regex_group_submatches:nNN* 定义结束。)

__regex_group_repeat_aux:n

Here we repeat \toks ranging from left_state to max_state, #1 > 0 times. First add a transition so that the copies “chain” properly. Compute the shift c between the original copy and the last copy we want. Shift the right_state and max_state to their final values. We then want to perform c copy operations. At the end, b is equal to the max_state, and a points to the left of the last copy of the group.

```
\cs_new_protected:Npn \__regex_group_repeat_aux:n #1
  {
    \__regex_build_transition_right:nNn \__regex_action_free:n
      \l__regex_right_state_int \l__regex_max_state_int
    \int_set_eq:NN \l__regex_internal_a_int \l__regex_left_state_int
  \int_set_eq:NN \l__regex_internal_b_int \l__regex_max_state_int
  \if_int_compare:w \int_eval:n {#1} > \c_one_int
   \int_set:Nn \l__regex_internal_c_int
    {
     ( #1 - 1 )
     * ( \l__regex_internal_b_int - \l__regex_internal_a_int )
    }
   \int_add:Nn \l__regex_right_state_int { \l__regex_internal_c_int }
   \int_add:Nn \l__regex_max_state_int   { \l__regex_internal_c_int }
   \__regex_toks_memcpy:NNn
    \l__regex_internal_b_int
    \l__regex_internal_a_int
    \l__regex_internal_c_int
  \fi:
 }
```

(__*regex*_*group*_*repeat*_*aux:n* 定义结束。)

__regex_group_repeat:nnN This function is called to repeat a group at least n times; the case $n = 0$ is very different from $n > 0$. Assume first that $n = 0$. Insert submatch tracking information at the start and end of the group, add a free transition from the right end to the "true" left state `a` (remember: in this case we had added an extra state before the left state). This forms the loop, which we break away from by adding a free transition from `a` to a new state.

Now consider the case $n > 0$. Repeat the group n times, chaining various copies with a free transition. Add submatch tracking only to the last copy, then add a free transition from the right end back to the left end of the last copy, either before or after the transition to move on towards the rest of the NFA. This transition can end up before submatch tracking, but that is irrelevant since it only does so when going again through the group, recording new matches. Finally, add a state; we already have a transition pointing to it from `\__regex_group_repeat_aux:n`.

```
\cs_new_protected:Npn \__regex_group_repeat:nnN #1#2#3
 {
  \if_int_compare:w #2 = \c_zero_int
   \__regex_group_submatches:nNN {#1}
    \l__regex_left_state_int \l__regex_right_state_int
   \int_set:Nn \l__regex_internal_a_int
    { \l__regex_left_state_int - 1 }
   \__regex_build_transition_right:nNn \__regex_action_free:n
    \l__regex_right_state_int \l__regex_internal_a_int
   \__regex_build_new_state:
      \if_meaning:w \c_true_bool #3
        \__regex_build_transition_left:NNN \__regex_action_free:n
          \l__regex_internal_a_int \l__regex_right_state_int
      \else:
        \__regex_build_transition_right:nNn \__regex_action_free:n
          \l__regex_internal_a_int \l__regex_right_state_int
      \fi:
    \else:
      \__regex_group_repeat_aux:n {#2}
      \__regex_group_submatches:nNN {#1}
        \l__regex_internal_a_int \l__regex_right_state_int
      \if_meaning:w \c_true_bool #3
        \__regex_build_transition_right:nNn \__regex_action_free_group:n
          \l__regex_right_state_int \l__regex_internal_a_int
      \else:
        \__regex_build_transition_left:NNN \__regex_action_free_group:n
          \l__regex_right_state_int \l__regex_internal_a_int
      \fi:
      \__regex_build_new_state:
    \fi:
  }
```

(*__regex_group_repeat:nnN 定义结束。*)

__regex_group_repeat:nnnN

We wish to repeat the group between #2 and #2+#3 times, with a lazyness controlled by #4. We insert submatch tracking up front: in principle, we could avoid recording submatches for the first #2 copies of the group, but that forces us to treat specially the case #2 $=0$. Repeat that group with submatch tracking #2 + #3 times (the maximum number of repetitions). Then our goal is to add #3 transitions from the end of the #2-th group, and each subsequent groups, to the end. For a lazy quantifier, we add those transitions to the left states, before submatch tracking. For the greedy case, we add the transitions to the right states, after submatch tracking and the transitions which go on with more repetitions. In the greedy case with #2 $=0$, the transition which skips over all copies of the group must be added separately, because its starting state does not follow the normal pattern: we had to add it "by hand" earlier.

```
\cs_new_protected:Npn \__regex_group_repeat:nnnN #1#2#3#4
  {
    \__regex_group_submatches:nNN {#1}
      \l__regex_left_state_int \l__regex_right_state_int
    \__regex_group_repeat_aux:n { #2 + #3 }
    \if_meaning:w \c_true_bool #4
      \int_set_eq:NN \l__regex_left_state_int \l__regex_max_state_int
      \prg_replicate:nn { #3 }
        {
          \int_sub:Nn \l__regex_left_state_int
            { \l__regex_internal_b_int - \l__regex_internal_a_int }
          \__regex_build_transition_left:NNN \__regex_action_free:n
            \l__regex_left_state_int \l__regex_max_state_int
        }
    \else:
      \prg_replicate:nn { #3 - 1 }
        {
          \int_sub:Nn \l__regex_right_state_int
            { \l__regex_internal_b_int - \l__regex_internal_a_int }
          \__regex_build_transition_right:nNn \__regex_action_free:n
            \l__regex_right_state_int \l__regex_max_state_int
        }
      \if_int_compare:w #2 = \c_zero_int
        \int_set:Nn \l__regex_right_state_int
          { \l__regex_left_state_int - 1 }
      \else:
        \int_sub:Nn \l__regex_right_state_int
          { \l__regex_internal_b_int - \l__regex_internal_a_int }
      \fi:
      \__regex_build_transition_right:nNn \__regex_action_free:n
        \l__regex_right_state_int \l__regex_max_state_int
    \fi:
    \__regex_build_new_state:
  }
```

(__*regex_group_repeat:nnnN* 定义结束。)

9.4.6 Others

__regex_assertion:Nn
__regex_b_test:
__regex_A_test:
__regex_G_test:
__regex_Z_test:

Usage: `\__regex_assertion:Nn` ⟨*boolean*⟩ {⟨*test*⟩}, where the ⟨*test*⟩ is either of the two other functions. Add a free transition to a new state, conditionally to the assertion test. The `\__regex_b_test:` test is used by the `\b` and `\B` escape: check if the last character was a word character or not, and do the same to the current character. The boundary-markers of the string are non-word characters for this purpose.

```
\cs_new_protected:Npn \__regex_assertion:Nn #1#2
  {
    \__regex_build_new_state:
    \__regex_toks_put_right:Ne \l__regex_left_state_int
      {
        \exp_not:n {#2}
        \__regex_break_point:TF
          \bool_if:NF #1 { { } }
          {
            \__regex_action_free:n
              {
                \int_eval:n
                  { \l__regex_right_state_int - \l__regex_left_state_int }
              }
          }
          \bool_if:NT #1 { { } }
      }
  }
\cs_new_protected:Npn \__regex_b_test:
  {
    \group_begin:
      \int_set_eq:NN \l__regex_curr_char_int \l__regex_last_char_int
      \__regex_prop_w:
      \__regex_break_point:TF
        { \group_end: \__regex_item_reverse:n { \__regex_prop_w: } }
        { \group_end: \__regex_prop_w: }
  }
\cs_new_protected:Npn \__regex_Z_test:
  {
    \if_int_compare:w -2 = \l__regex_curr_char_int
      \exp_after:wN \__regex_break_true:w
    \fi:
  }
\cs_new_protected:Npn \__regex_A_test:
  {
    \if_int_compare:w -2 = \l__regex_last_char_int
      \exp_after:wN \__regex_break_true:w
    \fi:
  }
\cs_new_protected:Npn \__regex_G_test:
  {
    \if_int_compare:w \l__regex_curr_pos_int = \l__regex_start_pos_int
      \exp_after:wN \__regex_break_true:w
    \fi:
  }
```

(*__regex_assertion:Nn* 以及其它的定义结束。)

__regex_command_K: Change the starting point of the 0-th submatch (full match), and transition to a new state, pretending that this is a fresh thread.

```
\cs_new_protected:Npn \__regex_command_K:
  {
    \__regex_build_new_state:
    \__regex_toks_put_right:Ne \l__regex_left_state_int
      {
        \__regex_action_submatch:nN { 0 } <
        \bool_set_true:N \l__regex_fresh_thread_bool
        \__regex_action_free:n
          {
            \int_eval:n
              { \l__regex_right_state_int - \l__regex_left_state_int }
          }
        \bool_set_false:N \l__regex_fresh_thread_bool
      }
  }
```

(*__regex_command_K:* 定义结束。)

9.5 Matching

We search for matches by running all the execution threads through the NFA in parallel, reading one token of the query at each step. The NFA contains “free” transitions to other states, and transitions which “consume” the current token. For free transitions, the instruction at the new state of the NFA is performed immediately. When a transition consumes a character, the new state is appended to a list of “active states”, stored in `\g__regex_thread_info_intarray` (together with submatch information): this thread is made active again when the next token is read from the query. At every step (for each token in the query), we unpack that list of active states and the corresponding submatch props, and empty those.

If two paths through the NFA “collide” in the sense that they reach the same state after reading a given token, then they only differ in how they previously matched, and any future execution would be identical for both. (Note that this would be wrong in the presence of back-references.) Hence, we only need to keep one of the two threads: the thread with the highest priority. Our NFA is built in such a way that higher priority actions always come before lower priority actions, which makes things work.

The explanation in the previous paragraph may make us think that we simply need to keep track of which states were visited at a given step: after all, the loop generated when matching `(a?)*` against `a` is broken, isn't it? No. The group first matches `a`, as it should, then repeats; it attempts to match `a` again but fails; it skips `a`, and finds out that this state has already been seen at this position in the query: the match stops. The capturing group is (wrongly) `a`. What went wrong is that a thread collided with itself, and the later version, which has gone through the group one more times with an empty match, should have a higher priority than not going through the group.

We solve this by distinguishing "normal" free transitions `\__regex_action_free:n` from transitions `\__regex_action_free_group:n` which go back to the start of the group. The former keeps threads unless they have been visited by a "completed" thread, while the latter kind of transition also prevents going back to a state visited by the current thread.

9.5.1 Variables used when matching

`\l__regex_min_pos_int`
`\l__regex_max_pos_int`
`\l__regex_curr_pos_int`
`\l__regex_start_pos_int`
`\l__regex_success_pos_int`

The tokens in the query are indexed from `min_pos` for the first to `max_pos` − 1 for the last, and their information is stored in several arrays and `\toks` registers with those numbers. We match without backtracking, keeping all threads in lockstep at the `curr_pos` in the query. The starting point of the current match attempt is `start_pos`, and `success_pos`, updated whenever a thread succeeds, is used as the next starting position.

```
\int_new:N \l__regex_min_pos_int
\int_new:N \l__regex_max_pos_int
\int_new:N \l__regex_curr_pos_int
\int_new:N \l__regex_start_pos_int
\int_new:N \l__regex_success_pos_int
```

(*\l__regex_min_pos_int* 以及其它的定义结束。)

`\l__regex_curr_char_int`
`\l__regex_curr_catcode_int`
`\l__regex_curr_token_tl`
`\l__regex_last_char_int`
`\l__regex_last_char_success_int`
`\l__regex_case_changed_char_int`

The character and category codes of the token at the current position and a token list expanding to that token; the character code of the token at the previous position; the character code of the token just before a successful match; and the character code of the result of changing the case of the current token (`A-Z`↔`a-z`). This last integer is only computed when necessary, and is otherwise `\c_max_int`. The `curr_char` variable is also used in various other phases to hold a character code.

```
\int_new:N \l__regex_curr_char_int
\int_new:N \l__regex_curr_catcode_int
\tl_new:N \l__regex_curr_token_tl
\int_new:N \l__regex_last_char_int
\int_new:N \l__regex_last_char_success_int
\int_new:N \l__regex_case_changed_char_int
```

(*\l__regex_curr_char_int* 以及其它的定义结束。)

\l__regex_curr_state_int

For every character in the token list, each of the active states is considered in turn. The variable `\l__regex_curr_state_int` holds the state of the NFA which is currently considered: transitions are then given as shifts relative to the current state.

```
\int_new:N \l__regex_curr_state_int
```

(*\l__regex_curr_state_int* 定义结束。)

\l__regex_curr_submatches_tl
\l__regex_success_submatches_tl

The submatches for the thread which is currently active are stored in the `curr_-submatches` list, which is almost a comma list, but ends with a comma. This list is stored by `\__regex_store_state:n` into an intarray variable, to be retrieved when matching at the next position. When a thread succeeds, this list is copied to `\l__regex_success_submatches_tl`: only the last successful thread remains there.

```
\tl_new:N \l__regex_curr_submatches_tl
\tl_new:N \l__regex_success_submatches_tl
```

(*\l__regex_curr_submatches_tl* 和 *\l__regex_success_submatches_tl* 定义结束。)

\l__regex_step_int

This integer, always even, is increased every time a character in the query is read, and not reset when doing multiple matches. We store in `\g__regex_state_active_-intarray` the last step in which each ⟨*state*⟩ in the NFA was encountered. This lets us break infinite loops by not visiting the same state twice in the same step. In fact, the step we store is equal to `step` when we have started performing the operations of `\toks`⟨*state*⟩, but not finished yet. However, once we finish, we store `step`+1 in `\g__regex_state_active_intarray`. This is needed to track submatches properly (see building phase). The `step` is also used to attach each set of submatch information to a given iteration (and automatically discard it when it corresponds to a past step).

```
\int_new:N \l__regex_step_int
```

(*\l__regex_step_int* 定义结束。)

\l__regex_min_thread_int
\l__regex_max_thread_int

All the currently active threads are kept in order of precedence in \g__regex_thread_info_intarray together with the corresponding submatch information. Data in this intarray is organized as blocks from min_thread (included) to max_thread (excluded). At the start of every step, the whole array is unpacked, so that the space can immediately be reused, and max_thread is reset to min_thread, effectively clearing the array.

```
\int_new:N \l__regex_min_thread_int
\int_new:N \l__regex_max_thread_int
```

(*\l__regex_min_thread_int* 和 *\l__regex_max_thread_int* 定义结束。)

\g__regex_state_active_intarray
\g__regex_thread_info_intarray

\g__regex_state_active_intarray stores the last ⟨*step*⟩ in which each ⟨*state*⟩ was active. \g__regex_thread_info_intarray stores threads to be considered in the next step, more precisely the states in which these threads are.

```
\intarray_new:Nn \g__regex_state_active_intarray { 65536 }
\intarray_new:Nn \g__regex_thread_info_intarray { 65536 }
```

(*\g__regex_state_active_intarray* 和 *\g__regex_thread_info_intarray* 定义结束。)

\l__regex_matched_analysis_tl
\l__regex_curr_analysis_tl

The list \l__regex_curr_analysis_tl consists of a brace group containing three brace groups corresponding to the current token, with the same syntax as \tl_analysis_map_inline:nn. The list \l__regex_matched_analysis_tl (constructed under the tl_build machinery) has one item for each token that has already been treated so far in a given match attempt: each item consists of three brace groups with the same syntax as \tl_analysis_map_inline:nn.

```
\tl_new:N \l__regex_matched_analysis_tl
\tl_new:N \l__regex_curr_analysis_tl
```

(*\l__regex_matched_analysis_tl* 和 *\l__regex_curr_analysis_tl* 定义结束。)

\l__regex_every_match_tl

Every time a match is found, this token list is used. For single matching, the token list is empty. For multiple matching, the token list is set to repeat the matching, after performing some operation which depends on the user function. See __regex_single_match: and __regex_multi_match:n.

```
\tl_new:N \l__regex_every_match_tl
```

(*\l__regex_every_match_tl* 定义结束。)

\l__regex_fresh_thread_bool
\l__regex_empty_success_bool
__regex_if_two_empty_matches:F

When doing multiple matches, we need to avoid infinite loops where each iteration matches the same empty token list. When an empty token list is matched, the next successful match of the same empty token list is suppressed. We detect empty matches by setting `\l__regex_fresh_thread_bool` to `true` for threads which directly come from the start of the regex or from the `\K` command, and testing that boolean whenever a thread succeeds. The function `\__regex_if_two_empty_matches:F` is redefined at every match attempt, depending on whether the previous match was empty or not: if it was, then the function must cancel a purported success if it is empty and at the same spot as the previous match; otherwise, we definitely don't have two identical empty matches, so the function is `\use:n`.

```
\bool_new:N \l__regex_fresh_thread_bool
\bool_new:N \l__regex_empty_success_bool
\cs_new_eq:NN \__regex_if_two_empty_matches:F \use:n
```

(*\l__regex_fresh_thread_bool*, *\l__regex_empty_success_bool*, 和 *__regex_if_two_empty_matches:F* 定义结束。)

\g__regex_success_bool
\l__regex_saved_success_bool
\l__regex_match_success_bool

The boolean `\l__regex_match_success_bool` is true if the current match attempt was successful, and `\g__regex_success_bool` is true if there was at least one successful match. This is the only global variable in this whole module, but we would need it to be local when matching a control sequence with `\c{...}`. This is done by saving the global variable into `\l__regex_saved_success_bool`, which is local, hence not affected by the changes due to inner regex functions.

```
\bool_new:N \g__regex_success_bool
\bool_new:N \l__regex_saved_success_bool
\bool_new:N \l__regex_match_success_bool
```

(*\g__regex_success_bool*, *\l__regex_saved_success_bool*, 和 *\l__regex_match_success_bool* 定义结束。)

9.5.2 Matching: framework

__regex_match:n
__regex_match_cs:n
__regex_match_init:

Initialize the variables that should be set once for each user function (even for multiple matches). Namely, the overall matching is not yet successful; none of the states should be marked as visited (`\g__regex_state_active_intarray`), and we start at step 0; we pretend that there was a previous match ending at the start of the query, which was not empty (to avoid smothering an empty match at the start). Once all this is set up, we are ready for the ride. Find the first match.

```
\cs_new_protected:Npn \__regex_match:n #1
  {
    \__regex_match_init:
```

```
    \__regex_match_once_init:
    \tl_analysis_map_inline:nn {#1}
      { \__regex_match_one_token:nnN {##1} {##2} ##3 }
    \__regex_match_one_token:nnN { } { -2 } F
    \prg_break_point:Nn \__regex_maplike_break: { }
  }
\cs_new_protected:Npn \__regex_match_cs:n #1
  {
    \int_set_eq:NN \l__regex_min_thread_int \l__regex_max_thread_int
    \__regex_match_init:
    \__regex_match_once_init:
    \str_map_inline:nn {#1}
      {
        \tl_if_blank:nTF {##1}
          { \__regex_match_one_token:nnN {##1} {`##1} A }
          { \__regex_match_one_token:nnN {##1} {`##1} C }
      }
    \__regex_match_one_token:nnN { } { -2 } F
    \prg_break_point:Nn \__regex_maplike_break: { }
  }
\cs_new_protected:Npn \__regex_match_init:
  {
    \bool_gset_false:N \g__regex_success_bool
    \int_step_inline:nnn
      \l__regex_min_state_int { \l__regex_max_state_int - 1 }
      {
        \__kernel_intarray_gset:Nnn
          \g__regex_state_active_intarray {##1} { 1 }
      }
    \int_zero:N \l__regex_step_int
    \int_set:Nn \l__regex_min_pos_int { 2 }
    \int_set_eq:NN \l__regex_success_pos_int \l__regex_min_pos_int
    \int_set:Nn \l__regex_last_char_success_int { -2 }
    \tl_build_begin:N \l__regex_matched_analysis_tl
    \tl_clear:N \l__regex_curr_analysis_tl
    \int_set:Nn \l__regex_min_submatch_int { 1 }
    \int_set_eq:NN \l__regex_submatch_int \l__regex_min_submatch_int
    \bool_set_false:N \l__regex_empty_success_bool
  }
```

(*__regex_match:n*, *__regex_match_cs:n*, 和 *__regex_match_init:* 定义结束。)

`\__regex_match_once_init:` This function resets various variables used when finding one match. It is called before the loop through characters, and every time we find a match, before searching for another match (this is controlled by the every_match token list).

First initialize some variables: set the conditional which detects identical empty matches; this match attempt starts at the previous success_pos, is not yet successful, and has no submatches yet; clear the array of active threads, and put the starting state 0 in it. We are then almost ready to read our first token in the query, but we actually start one position earlier than the start because __regex_match_one_token:nnN increments \l__regex_curr_pos_int and saves \l__regex_curr_char_int as the last_char so that word boundaries can be correctly identified.

```
\cs_new_protected:Npn \__regex_match_once_init:
  {
    \if_meaning:w \c_true_bool \l__regex_empty_success_bool
      \cs_set:Npn \__regex_if_two_empty_matches:F
        {
          \int_compare:nNnF
            \l__regex_start_pos_int = \l__regex_curr_pos_int
        }
    \else:
      \cs_set_eq:NN \__regex_if_two_empty_matches:F \use:n
    \fi:
    \int_set_eq:NN \l__regex_start_pos_int \l__regex_success_pos_int
    \bool_set_false:N \l__regex_match_success_bool
    \tl_set:Ne \l__regex_curr_submatches_tl
      { \prg_replicate:nn { 2 * \l__regex_capturing_group_int } { 0 , } }
    \int_set_eq:NN \l__regex_max_thread_int \l__regex_min_thread_int
    \__regex_store_state:n { \l__regex_min_state_int }
    \int_set:Nn \l__regex_curr_pos_int
      { \l__regex_start_pos_int - 1 }
    \int_set_eq:NN \l__regex_curr_char_int \l__regex_last_char_success_int
    \tl_build_get_intermediate:NN \l__regex_matched_analysis_tl \l__regex_internal_a_tl
    \exp_args:NNf \__regex_match_once_init_aux:
    \tl_map_inline:nn
      { \exp_after:wN \l__regex_internal_a_tl \l__regex_curr_analysis_tl }
      { \__regex_match_one_token:nnN ##1 }
    \prg_break_point:Nn \__regex_maplike_break: { }
  }
\cs_new_protected:Npn \__regex_match_once_init_aux:
  {
    \tl_build_begin:N \l__regex_matched_analysis_tl
    \tl_clear:N \l__regex_curr_analysis_tl
  }
```

(*__regex_match_once_init:* 定义结束。)

__regex_single_match:
__regex_multi_match:n

For a single match, the overall success is determined by whether the only match attempt is a success. When doing multiple matches, the overall matching is successful as soon as any match succeeds. Perform the action `#1`, then find the next match.

```
\cs_new_protected:Npn \__regex_single_match:
  {
    \tl_set:Nn \l__regex_every_match_tl
      {
        \bool_gset_eq:NN
          \g__regex_success_bool
          \l__regex_match_success_bool
        \__regex_maplike_break:
      }
  }
\cs_new_protected:Npn \__regex_multi_match:n #1
  {
    \tl_set:Nn \l__regex_every_match_tl
      {
        \if_meaning:w \c_false_bool \l__regex_match_success_bool
          \exp_after:wN \__regex_maplike_break:
        \fi:
        \bool_gset_true:N \g__regex_success_bool
        #1
        \__regex_match_once_init:
      }
  }
```

(*__regex_single_match:* 和 *__regex_multi_match:n* 定义结束。)

__regex_match_one_token:nnN
__regex_match_one_active:n

At each new position, set some variables and get the new character and category from the query. Then unpack the array of active threads, and clear it by resetting its length (`max_thread`). This results in a sequence of `\__regex_use_state_and_submatches:w` ⟨*state*⟩`,`⟨*submatch-clist*⟩`;` and we consider those states one by one in order. As soon as a thread succeeds, exit the step, and, if there are threads to consider at the next position, and we have not reached the end of the string, repeat the loop. Otherwise, the last thread that succeeded is the match. We explain the `fresh_thread` business when describing `\__regex_action_wildcard:`.

```
\cs_new_protected:Npn \__regex_match_one_token:nnN #1#2#3
  {
    \int_add:Nn \l__regex_step_int { 2 }
    \int_incr:N \l__regex_curr_pos_int
    \int_set_eq:NN \l__regex_last_char_int \l__regex_curr_char_int
    \cs_set_eq:NN \__regex_maybe_compute_ccc: \__regex_compute_case_changed_char:
    \tl_set:Nn \l__regex_curr_token_tl {#1}
    \int_set:Nn \l__regex_curr_char_int {#2}
    \int_set:Nn \l__regex_curr_catcode_int { "#3 }
    \tl_build_put_right:Ne \l__regex_matched_analysis_tl
      { \exp_not:o \l__regex_curr_analysis_tl }
    \tl_set:Nn \l__regex_curr_analysis_tl { { {#1} {#2} #3 } }
    \use:e
      {
        \int_set_eq:NN \l__regex_max_thread_int \l__regex_min_thread_int
        \int_step_function:nnN
          { \l__regex_min_thread_int }
          { \l__regex_max_thread_int - 1 }
          \__regex_match_one_active:n
      }
    \prg_break_point:
    \bool_set_false:N \l__regex_fresh_thread_bool
    \if_int_compare:w \l__regex_max_thread_int > \l__regex_min_thread_int
      \if_int_compare:w -2 < \l__regex_curr_char_int
        \exp_after:wN \exp_after:wN \exp_after:wN \use_none:n
      \fi:
    \fi:
    \l__regex_every_match_tl
  }
\cs_new:Npn \__regex_match_one_active:n #1
  {
    \__regex_use_state_and_submatches:w
    \__kernel_intarray_range_to_clist:Nnn
      \g__regex_thread_info_intarray
      { 1 + #1 * (\l__regex_capturing_group_int * 2 + 1) }
      { (1 + #1) * (\l__regex_capturing_group_int * 2 + 1) }
    ;
  }
```

(*__regex_match_one_token:nnN* 和 *__regex_match_one_active:n* 定义结束。)

9.5.3 Using states of the nfa

__regex_use_state: Use the current NFA instruction. The state is initially marked as belonging to the current `step`: this allows normal free transition to repeat, but group-repeating transitions won't. Once we are done exploring all the branches it spawned, the state is marked as `step` + 1: any thread hitting it at that point will be terminated.

```
\cs_new_protected:Npn \__regex_use_state:
  {
    \__kernel_intarray_gset:Nnn \g__regex_state_active_intarray
      { \l__regex_curr_state_int } { \l__regex_step_int }
    \__regex_toks_use:w \l__regex_curr_state_int
    \__kernel_intarray_gset:Nnn \g__regex_state_active_intarray
      { \l__regex_curr_state_int }
      { \int_eval:n { \l__regex_step_int + 1 } }
  }
```

(__*regex_use_state:* 定义结束。)

__regex_use_state_and_submatches:w

This function is called as one item in the array of active threads after that array has been unpacked for a new step. Update the `curr_state` and `curr_submatches` and use the state if it has not yet been encountered at this step.

```
\cs_new_protected:Npn \__regex_use_state_and_submatches:w #1 , #2 ;
  {
    \int_set:Nn \l__regex_curr_state_int {#1}
    \if_int_compare:w
        \__kernel_intarray_item:Nn \g__regex_state_active_intarray
          { \l__regex_curr_state_int }
                      < \l__regex_step_int
      \tl_set:Nn \l__regex_curr_submatches_tl { #2 , }
      \exp_after:wN \__regex_use_state:
    \fi:
    \scan_stop:
  }
```

(__*regex_use_state_and_submatches:w* 定义结束。)

9.5.4 Actions when matching

__regex_action_start_wildcard:N

For an unanchored match, state 0 has a free transition to the next and a costly one to itself, to repeat at the next position. To catch repeated identical empty matches, we need to know if a successful thread corresponds to an empty match. The instruction resetting `\l__regex_fresh_thread_bool` may be skipped by a successful thread, hence we had to add it to `\__regex_match_one_token:nnN` too.

```
\cs_new_protected:Npn \__regex_action_start_wildcard:N #1
  {
    \bool_set_true:N \l__regex_fresh_thread_bool
    \__regex_action_free:n {1}
    \bool_set_false:N \l__regex_fresh_thread_bool
    \bool_if:NT #1 { \__regex_action_cost:n {0} }
  }
```

(*__regex_action_start_wildcard:N* 定义结束。)

__regex_action_free:n
__regex_action_free_group:n
__regex_action_free_aux:nn

These functions copy a thread after checking that the NFA state has not already been used at this position. If not, store submatches in the new state, and insert the instructions for that state in the input stream. Then restore the old value of `\l__regex_curr_state_int` and of the current submatches. The two types of free transitions differ by how they test that the state has not been encountered yet: the `group` version is stricter, and will not use a state if it was used earlier in the current thread, hence forcefully breaking the loop, while the "normal" version will revisit a state even within the thread itself.

```
\cs_new_protected:Npn \__regex_action_free:n
  { \__regex_action_free_aux:nn { > \l__regex_step_int \else: } }
\cs_new_protected:Npn \__regex_action_free_group:n
  { \__regex_action_free_aux:nn { < \l__regex_step_int } }
\cs_new_protected:Npn \__regex_action_free_aux:nn #1#2
  {
    \use:e
      {
        \int_add:Nn \l__regex_curr_state_int {#2}
        \exp_not:n
          {
            \if_int_compare:w
                \__kernel_intarray_item:Nn \g__regex_state_active_intarray
                  { \l__regex_curr_state_int }
                #1
              \exp_after:wN \__regex_use_state:
            \fi:
          }
        \int_set:Nn \l__regex_curr_state_int
          { \int_use:N \l__regex_curr_state_int }
        \tl_set:Nn \exp_not:N \l__regex_curr_submatches_tl
          { \exp_not:o \l__regex_curr_submatches_tl }
      }
  }
```

(*__regex_action_free:n*, *__regex_action_free_group:n*, 和 *__regex_action_free_aux:nn* 定义结束。)

__regex_action_cost:n

A transition which consumes the current character and shifts the state by #1. The resulting state is stored in the appropriate array for use at the next position, and we also store the current submatches.

```
\cs_new_protected:Npn \__regex_action_cost:n #1
  {
    \exp_args:Ne \__regex_store_state:n
      { \int_eval:n { \l__regex_curr_state_int + #1 } }
  }
```

(*__regex_action_cost:n* 定义结束。)

__regex_store_state:n
__regex_store_submatches:

Put the given state and current submatch information in \g__regex_thread_info_intarray, and increment the length of the array.

```
\cs_new_protected:Npn \__regex_store_state:n #1
  {
    \exp_args:No \__regex_store_submatches:nn
      \l__regex_curr_submatches_tl {#1}
    \int_incr:N \l__regex_max_thread_int
  }
\cs_new_protected:Npn \__regex_store_submatches:nn #1#2
  {
    \__kernel_intarray_gset_range_from_clist:Nnn
      \g__regex_thread_info_intarray
      {
        \__regex_int_eval:w
        1 + \l__regex_max_thread_int *
        (\l__regex_capturing_group_int * 2 + 1)
      }
      { #2 , #1 }
  }
```

(*__regex_store_state:n* 和 *__regex_store_submatches:* 定义结束。)

__regex_disable_submatches:

Some user functions don't require tracking submatches. We get a performance improvement by simply defining the relevant functions to remove their argument and do nothing with it.

```
\cs_new_protected:Npn \__regex_disable_submatches:
  {
    \cs_set_protected:Npn \__regex_store_submatches:n ##1 { }
    \cs_set_protected:Npn \__regex_action_submatch:nN ##1##2 { }
  }
```

（__*regex_disable_submatches:* 定义结束。）

__regex_action_submatch:nN
__regex_action_submatch_aux:w
__regex_action_submatch_auxii:w
__regex_action_submatch_auxiii:w
__regex_action_submatch_auxiv:w

Update the current submatches with the information from the current position. Maybe a bottleneck.

```
\cs_new_protected:Npn \__regex_action_submatch:nN #1#2
  {
    \exp_after:wN \__regex_action_submatch_aux:w
    \l__regex_curr_submatches_tl ; {#1} #2
  }
\cs_new_protected:Npn \__regex_action_submatch_aux:w #1 ; #2#3
  {
    \tl_set:Ne \l__regex_curr_submatches_tl
      {
        \prg_replicate:nn
          { #2 \if_meaning:w > #3 + \l__regex_capturing_group_int \fi: }
          { \__regex_action_submatch_auxii:w }
        \__regex_action_submatch_auxiii:w
        #1
      }
  }
\cs_new:Npn \__regex_action_submatch_auxii:w
    #1 \__regex_action_submatch_auxiii:w #2 ,
  { #2 , #1 \__regex_action_submatch_auxiii:w }
\cs_new:Npn \__regex_action_submatch_auxiii:w #1 ,
  { \int_use:N \l__regex_curr_pos_int , }
```

（__*regex_action_submatch:nN* 以及其它的定义结束。）

__regex_action_success:

There is a successful match when an execution path reaches the last state in the NFA, unless this marks a second identical empty match. Then mark that there was a successful match; it is empty if it is “fresh”; and we store the current position and submatches. The current step is then interrupted with `\prg_break:`, and only paths with higher precedence are pursued further. The values stored here may be overwritten by a later success of a path with higher precedence.

```
\cs_new_protected:Npn \__regex_action_success:
  {
    \__regex_if_two_empty_matches:F
      {
        \bool_set_true:N \l__regex_match_success_bool
        \bool_set_eq:NN \l__regex_empty_success_bool
          \l__regex_fresh_thread_bool
        \int_set_eq:NN \l__regex_success_pos_int \l__regex_curr_pos_int
        \int_set_eq:NN \l__regex_last_char_success_int \l__regex_last_char_int
        \tl_build_begin:N \l__regex_matched_analysis_tl
        \tl_set_eq:NN \l__regex_success_submatches_tl
          \l__regex_curr_submatches_tl
        \prg_break:
      }
  }
```

(*__regex_action_success:* 定义结束。)

9.6 Replacement

9.6.1 Variables and helpers used in replacement

\l__regex_replacement_csnames_int The behaviour of closing braces inside a replacement text depends on whether a sequences `\c{` or `\u{` has been encountered. The number of “open” such sequences that should be closed by `}` is stored in `\l__regex_replacement_csnames_int`, and decreased by 1 by each `}`.

```
\int_new:N \l__regex_replacement_csnames_int
```

(*\l__regex_replacement_csnames_int* 定义结束。)

\l__regex_replacement_category_tl
\l__regex_replacement_category_seq This sequence of letters is used to correctly restore categories in nested constructions such as `\cL(abc\cD(_)d)`.

```
\tl_new:N \l__regex_replacement_category_tl
\seq_new:N \l__regex_replacement_category_seq
```

(*\l__regex_replacement_category_tl* 和 *\l__regex_replacement_category_seq* 定义结束。)

\g__regex_balance_tl This token list holds the replacement text for `\__regex_replacement_balance_one_match:n` while it is being built incrementally.

```
\tl_new:N \g__regex_balance_tl
```

(*\g__regex_balance_tl* 定义结束。)

__regex_replacement_balance_one_match:n This expects as an argument the first index of a set of entries in `\g__regex_submatch_begin_intarray` (and related arrays) which hold the submatch information for a given match. It can be used within an integer expression to obtain the brace balance incurred by performing the replacement on that match. This combines the braces lost by removing the match, braces added by all the submatches appearing in the replacement, and braces appearing explicitly in the replacement. Even though it is always redefined before use, we initialize it as for an empty replacement. An important property is that concatenating several calls to that function must result in a valid integer expression (hence a leading + in the actual definition).

```
\cs_new:Npn \__regex_replacement_balance_one_match:n #1
  { - \__regex_submatch_balance:n {#1} }
```

(*__regex_replacement_balance_one_match:n* 定义结束。)

__regex_replacement_do_one_match:n

The input is the same as `\__regex_replacement_balance_one_match:n`. This function is redefined to expand to the part of the token list from the end of the previous match to a given match, followed by the replacement text. Hence concatenating the result of this function with all possible arguments (one call for each match), as well as the range from the end of the last match to the end of the string, produces the fully replaced token list. The initialization does not matter, but (as an example) we set it as for an empty replacement.

```
\cs_new:Npn \__regex_replacement_do_one_match:n #1
  {
    \__regex_query_range:nn
      { \__kernel_intarray_item:Nn \g__regex_submatch_prev_intarray {#1} }
      { \__kernel_intarray_item:Nn \g__regex_submatch_begin_intarray {#1} }
  }
```

(*__regex_replacement_do_one_match:n* 定义结束。)

__regex_replacement_exp_not:N

This function lets us navigate around the fact that the primitive `\exp_not:n` requires a braced argument. As far as I can tell, it is only needed if the user tries to include in the replacement text a control sequence set equal to a macro parameter character, such as `\c_parameter_token`. Indeed, within an `e`/`x`-expanding assignment, `\exp_not:N #` behaves as a single `#`, whereas `\exp_not:n {#}` behaves as a doubled `##`.

```
\cs_new:Npn \__regex_replacement_exp_not:N #1 { \exp_not:n {#1} }
```

(*__regex_replacement_exp_not:N* 定义结束。)

__regex_replacement_exp_not:V

This is used for the implementation of `\u`, and it gets redefined for `\peek_regex_replace_once:nnTF`.

```
\cs_new_eq:NN \__regex_replacement_exp_not:V \exp_not:V
```

(*__regex_replacement_exp_not:V* 定义结束。)

9.6.2 Query and brace balance

__regex_query_range:nn
__regex_query_range_loop:ww

When it is time to extract submatches from the token list, the various tokens are stored in \toks registers numbered from \l__regex_min_pos_int inclusive to \l__regex_max_pos_int exclusive. The function __regex_query_range:nn {⟨*min*⟩} {⟨*max*⟩} unpacks registers from the position ⟨*min*⟩ to the position ⟨*max*⟩ -1 included. Once this is expanded, a second e-expansion results in the actual tokens from the query. That second expansion is only done by user functions at the very end of their operation, after checking (and correcting) the brace balance first.

```
\cs_new:Npn \__regex_query_range:nn #1#2
  {
    \exp_after:wN \__regex_query_range_loop:ww
    \int_value:w \__regex_int_eval:w #1 \exp_after:wN ;
    \int_value:w \__regex_int_eval:w #2 ;
    \prg_break_point:
  }
\cs_new:Npn \__regex_query_range_loop:ww #1 ; #2 ;
  {
    \if_int_compare:w #1 < #2 \exp_stop_f:
    \else:
      \exp_after:wN \prg_break:
    \fi:
    \__regex_toks_use:w #1 \exp_stop_f:
    \exp_after:wN \__regex_query_range_loop:ww
      \int_value:w \__regex_int_eval:w #1 + 1 ; #2 ;
  }
```

(__*regex_query_range:nn* 和 __*regex_query_range_loop:ww* 定义结束。)

__regex_query_submatch:n

Find the start and end positions for a given submatch (of a given match).

```
\cs_new:Npn \__regex_query_submatch:n #1
  {
    \__regex_query_range:nn
      { \__kernel_intarray_item:Nn \g__regex_submatch_begin_intarray {#1} }
      { \__kernel_intarray_item:Nn \g__regex_submatch_end_intarray {#1} }
  }
```

(__*regex_query_submatch:n* 定义结束。)

__regex_submatch_balance:n

Every user function must result in a balanced token list (unbalanced token lists cannot be stored by TeX). When we unpacked the query, we kept track of the brace balance, hence the contribution from a given range is the difference between the brace balances at the ⟨*max pos*⟩ and ⟨*min pos*⟩. These two positions are found in the corresponding "submatch" arrays.

```
\cs_new_protected:Npn \__regex_submatch_balance:n #1
  {
    \int_eval:n
      {
        \__regex_intarray_item:NnF \g__regex_balance_intarray
          {
            \__kernel_intarray_item:Nn
              \g__regex_submatch_end_intarray {#1}
          }
          { 0 }
        -
        \__regex_intarray_item:NnF \g__regex_balance_intarray
          {
            \__kernel_intarray_item:Nn
              \g__regex_submatch_begin_intarray {#1}
          }
          { 0 }
      }
  }
```

(`\__regex_submatch_balance:n` 定义结束。)

9.6.3 Framework

`\__regex_replacement:n`
`\__regex_replacement:e`
`\__regex_replacement_apply:Nn`
`\__regex_replacement_set:n`

The replacement text is built incrementally. We keep track in `\l__regex_balance_int` of the balance of explicit begin- and end-group tokens and we store in `\g__regex_balance_tl` some code to compute the brace balance from submatches (see its description). Detect unescaped right braces, and escaped characters, with trailing `\prg_do_nothing:` because some of the later function look-ahead. Once the whole replacement text has been parsed, make sure that there is no open csname. Finally, define the `balance_one_match` and `do_one_match` functions.

```
\cs_new_protected:Npn \__regex_replacement:n
  { \__regex_replacement_apply:Nn \__regex_replacement_set:n }
\cs_new_protected:Npn \__regex_replacement_apply:Nn #1#2
  {
    \group_begin:
      \tl_build_begin:N \l__regex_build_tl
      \int_zero:N \l__regex_balance_int
      \tl_gclear:N \g__regex_balance_tl
      \__regex_escape_use:nnnn
        {
          \if_charcode:w \c_right_brace_str ##1
            \__regex_replacement_rbrace:N
          \else:
            \if_charcode:w \c_left_brace_str ##1
              \__regex_replacement_lbrace:N
            \else:
              \__regex_replacement_normal:n
            \fi:
          \fi:
          ##1
        }
        { \__regex_replacement_escaped:N ##1 }
        { \__regex_replacement_normal:n ##1 }
        {#2}
      \prg_do_nothing: \prg_do_nothing:
      \if_int_compare:w \l__regex_replacement_csnames_int > \c_zero_int
        \msg_error:nne { regex } { replacement-missing-rbrace }
          { \int_use:N \l__regex_replacement_csnames_int }
        \tl_build_put_right:Ne \l__regex_build_tl
          { \prg_replicate:nn \l__regex_replacement_csnames_int \cs_end: }
      \fi:
      \seq_if_empty:NF \l__regex_replacement_category_seq
        {
          \msg_error:nne { regex } { replacement-missing-rparen }
            { \seq_count:N \l__regex_replacement_category_seq }
          \seq_clear:N \l__regex_replacement_category_seq
        }
      \tl_gput_right:Ne \g__regex_balance_tl
        { + \int_use:N \l__regex_balance_int }
      \tl_build_end:N \l__regex_build_tl
      \exp_args:NNo
    \group_end:
    #1 \l__regex_build_tl
  }
\cs_generate_variant:Nn \__regex_replacement:n { e }
\cs_new_protected:Npn \__regex_replacement_set:n #1
  {
    \cs_set:Npn \__regex_replacement_do_one_match:n ##1
      {
        \__regex_query_range:nn
```

```
          {
            \__kernel_intarray_item:Nn
              \g__regex_submatch_prev_intarray {##1}
          }
          {
            \__kernel_intarray_item:Nn
              \g__regex_submatch_begin_intarray {##1}
          }
        #1
      }
    \exp_args:Nno \use:n
      { \cs_gset:Npn \__regex_replacement_balance_one_match:n ##1 }
      {
        \g__regex_balance_tl
        - \__regex_submatch_balance:n {##1}
      }
  }
```

(__regex_replacement:n, __regex_replacement_apply:Nn, 和 __regex_replacement_set:n 定义结束。)

__regex_case_replacement:n
__regex_case_replacement:e

```
\tl_new:N \g__regex_case_replacement_tl
\tl_new:N \g__regex_case_balance_tl
\cs_new_protected:Npn \__regex_case_replacement:n #1
  {
    \tl_gset:Nn \g__regex_case_balance_tl
      {
        \if_case:w
          \__kernel_intarray_item:Nn
            \g__regex_submatch_case_intarray {##1}
      }
    \tl_gset_eq:NN \g__regex_case_replacement_tl \g__regex_case_balance_tl
    \tl_map_tokens:nn {#1}
      { \__regex_replacement_apply:Nn \__regex_case_replacement_aux:n }
    \tl_gset:No \g__regex_balance_tl
      { \g__regex_case_balance_tl \fi: }
    \exp_args:No \__regex_replacement_set:n
      { \g__regex_case_replacement_tl \fi: }
  }
\cs_generate_variant:Nn \__regex_case_replacement:n { e }
\cs_new_protected:Npn \__regex_case_replacement_aux:n #1
  {
    \tl_gput_right:Nn \g__regex_case_replacement_tl { \or: #1 }
    \tl_gput_right:No \g__regex_case_balance_tl
      { \exp_after:wN \or: \g__regex_balance_tl }
  }
```

(*__regex_case_replacement:n* 定义结束。)

__regex_replacement_put:n

This gets redefined for \peek_regex_replace_once:nnTF.

```
\cs_new_protected:Npn \__regex_replacement_put:n
  { \tl_build_put_right:Nn \l__regex_build_tl }
```

(*__regex_replacement_put:n* 定义结束。)

__regex_replacement_normal:n
__regex_replacement_normal_aux:N

Most characters are simply sent to the output by \tl_build_put_right:Nn, unless a particular category code has been requested: then __regex_replacement_c_A:w or a similar auxiliary is called. One exception is right parentheses, which restore the category code in place before the group started. Note that the sequence is non-empty there: it contains an empty entry corresponding to the initial value of \l__regex_replacement_category_tl. The argument #1 is a single character (including the case of a catcode-other space). In case no specific catcode is requested, we taked into account the current catcode regime (at the time the replacement is performed) as much as reasonable, with all impossible catcodes (escape, newline, etc.) being mapped to "other".

```
\cs_new_protected:Npn \__regex_replacement_normal:n #1
  {
    \int_compare:nNnTF { \l__regex_replacement_csnames_int } > 0
      { \exp_args:No \__regex_replacement_put:n { \token_to_str:N #1 } }
      {
        \tl_if_empty:NTF \l__regex_replacement_category_tl
          { \__regex_replacement_normal_aux:N #1 }
          { % (
            \token_if_eq_charcode:NNTF #1 )
              {
                \seq_pop:NN \l__regex_replacement_category_seq
                  \l__regex_replacement_category_tl
              }
              {
                \use:c { __regex_replacement_c_ \l__regex_replacement_category_tl :w }
                ? #1
              }
          }
      }
  }
```

```
\cs_new_protected:Npn \__regex_replacement_normal_aux:N #1
  {
    \token_if_eq_charcode:NNTF #1 \c_space_token
      { \__regex_replacement_c_S:w }
      {
        \exp_after:wN \exp_after:wN
        \if_case:w \tex_catcode:D `#1 \exp_stop_f:
             \__regex_replacement_c_O:w
        \or: \__regex_replacement_c_B:w
        \or: \__regex_replacement_c_E:w
        \or: \__regex_replacement_c_M:w
        \or: \__regex_replacement_c_T:w
        \or: \__regex_replacement_c_O:w
        \or: \__regex_replacement_c_P:w
        \or: \__regex_replacement_c_U:w
        \or: \__regex_replacement_c_D:w
        \or: \__regex_replacement_c_O:w
        \or: \__regex_replacement_c_S:w
        \or: \__regex_replacement_c_L:w
        \or: \__regex_replacement_c_O:w
        \or: \__regex_replacement_c_A:w
        \else: \__regex_replacement_c_O:w
        \fi:
      }
    ? #1
  }
```

(*__regex_replacement_normal:n* 和 *__regex_replacement_normal_aux:N* 定义结束。)

__regex_replacement_escaped:N

As in parsing a regular expression, we use an auxiliary built from #1 if defined. Otherwise, check for escaped digits (standing from submatches from 0 to 9): anything else is a raw character.

```
\cs_new_protected:Npn \__regex_replacement_escaped:N #1
  {
    \cs_if_exist_use:cF { __regex_replacement_#1:w }
      {
        \if_int_compare:w 1 < 1#1 \exp_stop_f:
          \__regex_replacement_put_submatch:n {#1}
        \else:
          \__regex_replacement_normal:n {#1}
        \fi:
      }
  }
```

(*__regex_replacement_escaped:N* 定义结束。)

9.6.4 Submatches

__regex_replacement_put_submatch:n
__regex_replacement_put_submatch_aux:n

Insert a submatch in the replacement text. This is dropped if the submatch number is larger than the number of capturing groups. Unless the submatch appears inside a `\c{...}` or `\u{...}` construction, it must be taken into account in the brace balance. Later on, `##1` will be replaced by a pointer to the 0-th submatch for a given match.

```
\cs_new_protected:Npn \__regex_replacement_put_submatch:n #1
  {
    \if_int_compare:w #1 < \l__regex_capturing_group_int
      \__regex_replacement_put_submatch_aux:n {#1}
    \else:
      \msg_expandable_error:nnff { regex } { submatch-too-big }
        {#1} { \int_eval:n { \l__regex_capturing_group_int - 1 } }
    \fi:
  }
\cs_new_protected:Npn \__regex_replacement_put_submatch_aux:n #1
  {
    \tl_build_put_right:Nn \l__regex_build_tl
      { \__regex_query_submatch:n { \int_eval:n { #1 + ##1 } } }
    \if_int_compare:w \l__regex_replacement_csnames_int = \c_zero_int
      \tl_gput_right:Nn \g__regex_balance_tl
        { + \__regex_submatch_balance:n { \int_eval:n { #1 + ##1 } } }
    \fi:
  }
```

(*__regex_replacement_put_submatch:n* 和 *__regex_replacement_put_submatch_aux:n* 定义结束。)

__regex_replacement_g:w
__regex_replacement_g_digits:NN

Grab digits for the `\g` escape sequence in a primitive assignment to the integer `\l__regex_internal_a_int`. At the end of the run of digits, check that it ends with a right brace.

```
\cs_new_protected:Npn \__regex_replacement_g:w #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_replacement_lbrace:N
      { \l__regex_internal_a_int = \__regex_replacement_g_digits:NN }
      { \__regex_replacement_error:NNN g #1 #2 }
  }
\cs_new:Npn \__regex_replacement_g_digits:NN #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_replacement_normal:n
      {
        \if_int_compare:w 1 < 1#2 \exp_stop_f:
          #2
          \exp_after:wN \use_i:nnn
          \exp_after:wN \__regex_replacement_g_digits:NN
        \else:
          \exp_stop_f:
          \exp_after:wN \__regex_replacement_error:NNN
          \exp_after:wN g
        \fi:
      }
      {
        \exp_stop_f:
        \if_meaning:w \__regex_replacement_rbrace:N #1
          \exp_args:No \__regex_replacement_put_submatch:n
            { \int_use:N \l__regex_internal_a_int }
          \exp_after:wN \use_none:nn
        \else:
          \exp_after:wN \__regex_replacement_error:NNN
          \exp_after:wN g
        \fi:
      }
    #1 #2
  }
```

(*__regex_replacement_g:w* 和 *__regex_replacement_g_digits:NN* 定义结束。)

9.6.5 Csnames in replacement

__regex_replacement_c:w

\c may only be followed by an unescaped character. If followed by a left brace, start a control sequence by calling an auxiliary common with \u. Otherwise test whether the category is known; if it is not, complain.

```
\cs_new_protected:Npn \__regex_replacement_c:w #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_replacement_normal:n
      {
        \cs_if_exist:cTF { __regex_replacement_c_#2:w }
          { \__regex_replacement_cat:NNN #2 }
          { \__regex_replacement_error:NNN c #1#2 }
      }
      {
        \token_if_eq_meaning:NNTF #1 \__regex_replacement_lbrace:N
          { \__regex_replacement_cu_aux:Nw \__regex_replacement_exp_not:N }
          { \__regex_replacement_error:NNN c #1#2 }
      }
  }
```

(__*regex_replacement_c:w* 定义结束。)

__regex_replacement_cu_aux:Nw

Start a control sequence with \cs:w, protected from expansion by #1 (either __regex_replacement_exp_not:N or \exp_not:V), or turned to a string by \tl_to_str:V if inside another csname construction \c or \u. We use \tl_to_str:V rather than \tl_to_str:N to deal with integers and other registers.

```
\cs_new_protected:Npn \__regex_replacement_cu_aux:Nw #1
  {
    \if_case:w \l__regex_replacement_csnames_int
      \tl_build_put_right:Nn \l__regex_build_tl
        { \exp_not:n { \exp_after:wN #1 \cs:w } }
    \else:
      \tl_build_put_right:Nn \l__regex_build_tl
        { \exp_not:n { \exp_after:wN \tl_to_str:V \cs:w } }
    \fi:
    \int_incr:N \l__regex_replacement_csnames_int
  }
```

(__*regex_replacement_cu_aux:Nw* 定义结束。)

__regex_replacement_u:w

Check that \u is followed by a left brace. If so, start a control sequence with \cs:w, which is then unpacked either with \exp_not:V or \tl_to_str:V depending on the current context.

```
\cs_new_protected:Npn \__regex_replacement_u:w #1#2
  {
    \token_if_eq_meaning:NNTF #1 \__regex_replacement_lbrace:N
      { \__regex_replacement_cu_aux:Nw \__regex_replacement_exp_not:V }
      { \__regex_replacement_error:NNN u #1#2 }
  }
```

(__*regex_replacement_u:w* 定义结束。)

__regex_replacement_rbrace:N

Within a \c{...} or \u{...} construction, end the control sequence, and decrease the brace count. Otherwise, this is a raw right brace.

```
\cs_new_protected:Npn \__regex_replacement_rbrace:N #1
  {
    \if_int_compare:w \l__regex_replacement_csnames_int > \c_zero_int
      \tl_build_put_right:Nn \l__regex_build_tl { \cs_end: }
      \int_decr:N \l__regex_replacement_csnames_int
    \else:
      \__regex_replacement_normal:n {#1}
    \fi:
  }
```

(*__regex_replacement_rbrace:N* 定义结束。)

__regex_replacement_lbrace:N

Within a \c{...} or \u{...} construction, this is forbidden. Otherwise, this is a raw left brace.

```
\cs_new_protected:Npn \__regex_replacement_lbrace:N #1
  {
    \if_int_compare:w \l__regex_replacement_csnames_int > \c_zero_int
      \msg_error:nnn { regex } { cu-lbrace } { u }
    \else:
      \__regex_replacement_normal:n {#1}
    \fi:
  }
```

(*__regex_replacement_lbrace:N* 定义结束。)

9.6.6 Characters in replacement

__regex_replacement_cat:NNN

Here, #1 is a letter among BEMTPUDSLOA and #2#3 denote the next character. Complain if we reach the end of the replacement or if the construction appears inside \c{…} or \u{…}, and detect the case of a parenthesis. In that case, store the current category in a sequence and switch to a new one.

```
\cs_new_protected:Npn \__regex_replacement_cat:NNN #1#2#3
  {
    \token_if_eq_meaning:NNTF \prg_do_nothing: #3
      { \msg_error:nn { regex } { replacement-catcode-end } }
      {
        \int_compare:nNnTF { \l__regex_replacement_csnames_int } > 0
          {
            \msg_error:nnnn
              { regex } { replacement-catcode-in-cs } {#1} {#3}
            #2 #3
          }
          {
            \__regex_two_if_eq:NNNNTF #2 #3 \__regex_replacement_normal:n (
              {
                \seq_push:NV \l__regex_replacement_category_seq
                \l__regex_replacement_category_tl
              \tl_set:Nn \l__regex_replacement_category_tl {#1}
            }
            {
              \token_if_eq_meaning:NNT #2 \__regex_replacement_escaped:N
                {
                  \__regex_char_if_alphanumeric:NTF #3
                    {
                      \msg_error:nnnn
                        { regex } { replacement-catcode-escaped }
                        {#1} {#3}
                    }
                    { }
                }
              \use:c { __regex_replacement_c_#1:w } #2 #3
            }
        }
    }
}
```

(__*regex*_*replacement*_*cat:NNN* 定义结束。)

We now need to change the category code of the null character many times, hence work in a group. The catcode-specific macros below are defined in alphabetical order; if you are trying to understand the code, start from the end of the alphabet as those categories are simpler than active or begin-group.

```
\group_begin:
```

__regex_replacement_char:nNN

The only way to produce an arbitrary character–catcode pair is to use the `\lowercase` or `\uppercase` primitives. This is a wrapper for our purposes. The first argument is the null character with various catcodes. The second and third arguments are grabbed from the input stream: `#3` is the character whose character code to reproduce. We could use `\char_generate:nn` but only for some catcodes (active characters and spaces are not supported).

```
\cs_new_protected:Npn \__regex_replacement_char:nNN #1#2#3
  {
    \tex_lccode:D 0 = `#3 \scan_stop:
    \tex_lowercase:D { \__regex_replacement_put:n {#1} }
  }
```

(__*regex*_*replacement*_*char:nNN* 定义结束。)

__regex_replacement_c_A:w

For an active character, expansion must be avoided, twice because we later do two e-expansions, to unpack \toks for the query, and to expand their contents to tokens of the query.

```
\char_set_catcode_active:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_A:w
  { \__regex_replacement_char:nNN { \exp_not:n { \exp_not:N ^^@ } } }
```

(*__regex_replacement_c_A:w* 定义结束。)

__regex_replacement_c_B:w

An explicit begin-group token increases the balance, unless within a \c{...} or \u{...} construction. Add the desired begin-group character, using the standard \if_false: trick. We eventually e-expand twice. The first time must yield a balanced token list, and the second one gives the bare begin-group token. The \exp_after:wN is not strictly needed, but is more consistent with l3tl-analysis.

```
\char_set_catcode_group_begin:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_B:w
  {
    \if_int_compare:w \l__regex_replacement_csnames_int = \c_zero_int
      \int_incr:N \l__regex_balance_int
    \fi:
    \__regex_replacement_char:nNN
      { \exp_not:n { \exp_after:wN ^^@ \if_false: } \fi: } }
  }
```

(*__regex_replacement_c_B:w* 定义结束。)

__regex_replacement_c_C:w

This is not quite catcode-related: when the user requests a character with category "control sequence", the one-character control symbol is returned. As for the active character, we prepare for two e-expansions.

```
\cs_new_protected:Npn \__regex_replacement_c_C:w #1#2
  {
    \tl_build_put_right:Nn \l__regex_build_tl
      { \exp_not:N \__regex_replacement_exp_not:N \exp_not:c {#2} }
  }
```

(*__regex_replacement_c_C:w* 定义结束。)

__regex_replacement_c_D:w

Subscripts fit the mould: \lowercase the null byte with the correct category.

```
\char_set_catcode_math_subscript:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_D:w
  { \__regex_replacement_char:nNN { ^^@ } }
```

（__regex_replacement_c_D:w 定义结束。）

__regex_replacement_c_E:w Similar to the begin-group case, the second e-expansion produces the bare end-group token.

```
\char_set_catcode_group_end:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_E:w
  {
    \if_int_compare:w \l__regex_replacement_csnames_int = \c_zero_int
      \int_decr:N \l__regex_balance_int
    \fi:
    \__regex_replacement_char:nNN
      { \exp_not:n { \if_false: { \fi:  ^^@ } }
  }
```

（__regex_replacement_c_E:w 定义结束。）

__regex_replacement_c_L:w Simply \lowercase a letter null byte to produce an arbitrary letter.

```
\char_set_catcode_letter:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_L:w
  { \__regex_replacement_char:nNN { ^^@ } }
```

（__regex_replacement_c_L:w 定义结束。）

__regex_replacement_c_M:w No surprise here, we lowercase the null math toggle.

```
\char_set_catcode_math_toggle:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_M:w
  { \__regex_replacement_char:nNN { ^^@ } }
```

（__regex_replacement_c_M:w 定义结束。）

__regex_replacement_c_O:w Lowercase an other null byte.

```
\char_set_catcode_other:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_O:w
  { \__regex_replacement_char:nNN { ^^@ } }
```

（__regex_replacement_c_O:w 定义结束。）

__regex_replacement_c_P:w For macro parameters, expansion is a tricky issue. We need to prepare for two e-expansions and passing through various macro definitions. Note that we cannot replace one \exp_not:n by doubling the macro parameter characters because this would misbehave if a mischievous user asks for \c{\cP\#}, since that macro parameter character would be doubled.

```
\char_set_catcode_parameter:N \^^@
```

```
\cs_new_protected:Npn \__regex_replacement_c_P:w
  {
    \__regex_replacement_char:nNN
      { \exp_not:n { \exp_not:n { ^^@^^@^^@^^@ } } }
  }
```

(*__regex_replacement_c_P:w* 定义结束。)

__regex_replacement_c_S:w

Spaces are normalized on input by TEX to have character code 32. It is in fact impossible to get a token with character code 0 and category code 10. Hence we use 32 instead of 0 as our base character.

```
\cs_new_protected:Npn \__regex_replacement_c_S:w #1#2
  {
    \if_int_compare:w `#2 = \c_zero_int
      \msg_error:nn { regex } { replacement-null-space }
    \fi:
    \tex_lccode:D `\ = `#2 \scan_stop:
    \tex_lowercase:D { \__regex_replacement_put:n {~} }
  }
```

(*__regex_replacement_c_S:w* 定义结束。)

__regex_replacement_c_T:w

No surprise for alignment tabs here. Those are surrounded by the appropriate braces whenever necessary, hence they don't cause trouble in alignment settings.

```
\char_set_catcode_alignment:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_T:w
  { \__regex_replacement_char:nNN { ^^@ } }
```

(*__regex_replacement_c_T:w* 定义结束。)

__regex_replacement_c_U:w

Simple call to `\__regex_replacement_char:nNN` which lowercases the math superscript `^^@`.

```
\char_set_catcode_math_superscript:N \^^@
\cs_new_protected:Npn \__regex_replacement_c_U:w
  { \__regex_replacement_char:nNN { ^^@ } }
```

(*__regex_replacement_c_U:w* 定义结束。)

Restore the catcode of the null byte.

```
\group_end:
```

9.6.7 An error

__regex_replacement_error:NNN

Simple error reporting by calling one of the messages `replacement-c`, `replacement-g`, or `replacement-u`.

```
\cs_new_protected:Npn \__regex_replacement_error:NNN #1#2#3
  {
    \msg_error:nne { regex } { replacement-#1 } {#3}
    #2 #3
  }
```

(*__regex_replacement_error:NNN* 定义结束。)

9.7 User functions

\regex_new:N

Before being assigned a sensible value, a regex variable matches nothing.

```
\cs_new_protected:Npn \regex_new:N #1
  { \cs_new_eq:NN #1 \c__regex_no_match_regex }
```

(*\regex_new:N* 定义结束。这个函数被记录在第*12*页。)

\l_tmpa_regex
\l_tmpb_regex
\g_tmpa_regex
\g_tmpb_regex

The usual scratch space.

```
\regex_new:N \l_tmpa_regex
\regex_new:N \l_tmpb_regex
\regex_new:N \g_tmpa_regex
\regex_new:N \g_tmpb_regex
```

(*\l_tmpa_regex* 以及其它的定义结束。这些变量被记录在第*18*页。)

\regex_set:Nn
\regex_gset:Nn
\regex_const:Nn

Compile, then store the result in the user variable with the appropriate assignment function.

```
\cs_new_protected:Npn \regex_set:Nn #1#2
  {
    \__regex_compile:n {#2}
    \tl_set_eq:NN #1 \l__regex_internal_regex
  }
\cs_new_protected:Npn \regex_gset:Nn #1#2
  {
    \__regex_compile:n {#2}
    \tl_gset_eq:NN #1 \l__regex_internal_regex
  }
\cs_new_protected:Npn \regex_const:Nn #1#2
  {
    \__regex_compile:n {#2}
    \tl_const:Ne #1 { \exp_not:o \l__regex_internal_regex }
  }
```

(*\regex_set:Nn*, *\regex_gset:Nn*, 和 *\regex_const:Nn* 定义结束。这些函数被记录在第13页。)

`\regex_show:n`
`\regex_log:n`
`\__regex_show:Nn`
`\regex_show:N`
`\regex_log:N`
`\__regex_show:NN`

User functions: the `n` variant requires compilation first. Then show the variable with some appropriate text. The auxiliary `\__regex_show:N` is defined in a different section.

```
\cs_new_protected:Npn \regex_show:n { \__regex_show:Nn \msg_show:nneeee }
\cs_new_protected:Npn \regex_log:n { \__regex_show:Nn \msg_log:nneeee }
\cs_new_protected:Npn \__regex_show:Nn #1#2
  {
    \__regex_compile:n {#2}
    \__regex_show:N \l__regex_internal_regex
    #1 { regex } { show }
      { \tl_to_str:n {#2} } { }
      { \l__regex_internal_a_tl } { }
  }
\cs_new_protected:Npn \regex_show:N { \__regex_show:NN \msg_show:nneeee }
\cs_new_protected:Npn \regex_log:N { \__regex_show:NN \msg_log:nneeee }
\cs_new_protected:Npn \__regex_show:NN #1#2
  {
    \__kernel_chk_tl_type:NnnT #2 { regex }
      { \exp_args:No \__regex_clean_regex:n {#2} }
      {
        \__regex_show:N #2
        #1 { regex } { show }
          { } { \token_to_str:N #2 }
          { \l__regex_internal_a_tl } { }
      }
  }
```

(*\regex_show:n* 以及其它的定义结束。这些函数被记录在第13页。)

`\regex_match:nn`*TF*
`\regex_match:nV`*TF*
`\regex_match:Nn`*TF*
`\regex_match:NV`*TF*

Those conditionals are based on a common auxiliary defined later. Its first argument builds the NFA corresponding to the regex, and the second argument is the query token list. Once we have performed the match, convert the resulting boolean to `\prg_return_true:` or `false`.

```
\prg_new_protected_conditional:Npnn \regex_match:nn #1#2 { T , F , TF }
  {
    \__regex_if_match:nn { \__regex_build:n {#1} } {#2}
    \__regex_return:
  }
\prg_generate_conditional_variant:Nnn \regex_match:nn { nV } { T , F , TF }
\prg_new_protected_conditional:Npnn \regex_match:Nn #1#2 { T , F , TF }
  {
    \__regex_if_match:nn { \__regex_build:N #1 } {#2}
    \__regex_return:
  }
\prg_generate_conditional_variant:Nnn \regex_match:Nn { NV } { T , F , TF }
```

(\regex_match:nnTF 和 \regex_match:NnTF 定义结束。这些函数被记录在第13页。)

\regex_count:nnN
\regex_count:nVN
\regex_count:NnN
\regex_count:NVN

Again, use an auxiliary whose first argument builds the NFA.

```
\cs_new_protected:Npn \regex_count:nnN #1
  { \__regex_count:nnN { \__regex_build:n {#1} } }
\cs_new_protected:Npn \regex_count:NnN #1
  { \__regex_count:nnN { \__regex_build:N #1 } }
\cs_generate_variant:Nn \regex_count:nnN { nV }
\cs_generate_variant:Nn \regex_count:NnN { NV }
```

(\regex_count:nnN 和 \regex_count:NnN 定义结束。这些函数被记录在第14页。)

\regex_match_case:nn
\regex_match_case:nnTF

The auxiliary errors if `#1` has an odd number of items, and otherwise it sets `\g__regex_case_int` according to which case was found (zero if not found). The `true` branch leaves the corresponding code in the input stream.

```
\cs_new_protected:Npn \regex_match_case:nnTF #1#2#3
  {
    \__regex_match_case:nnTF {#1} {#2}
      {
        \tl_item:nn {#1} { 2 * \g__regex_case_int }
        #3
      }
  }
\cs_new_protected:Npn \regex_match_case:nn #1#2
  { \regex_match_case:nnTF {#1} {#2} { } { } }
\cs_new_protected:Npn \regex_match_case:nnT #1#2#3
  { \regex_match_case:nnTF {#1} {#2} {#3} { } }
\cs_new_protected:Npn \regex_match_case:nnF #1#2
  { \regex_match_case:nnTF {#1} {#2} { } }
```

(\regex_match_case:nnTF 定义结束。这个函数被记录在第14页。)

\regex_extract_once:nnN
\regex_extract_once:nVN
\regex_extract_once:nnNTF
\regex_extract_once:nVNTF
\regex_extract_once:NnN
\regex_extract_once:NVN
\regex_extract_once:NnNTF
\regex_extract_once:NVNTF
\regex_extract_all:nnN

We define here 40 user functions, following a common pattern in terms of `:nnN` auxiliaries, defined in the coming subsections. The auxiliary is handed `\__regex_build:n` or `\__regex_build:N` with the appropriate regex argument, then all other necessary arguments (replacement text, token list, *etc.* The conditionals call `\__regex_return:` to return either `true` or `false` once matching has been performed.

```
\cs_set_protected:Npn \__regex_tmp:w #1#2#3
  {
    \cs_new_protected:Npn #2 ##1 { #1 { \__regex_build:n {##1} } }
    \cs_new_protected:Npn #3 ##1 { #1 { \__regex_build:N  ##1  } }
    \prg_new_protected_conditional:Npnn #2 ##1##2##3 { T , F , TF }
      { #1 { \__regex_build:n {##1} } {##2} ##3 \__regex_return: }
    \prg_new_protected_conditional:Npnn #3 ##1##2##3 { T , F , TF }
      { #1 { \__regex_build:N  ##1  } {##2} ##3 \__regex_return: }
    \cs_generate_variant:Nn #2 { nV }
    \prg_generate_conditional_variant:Nnn #2 { nV } { T , F , TF }
    \cs_generate_variant:Nn #3 { NV }
    \prg_generate_conditional_variant:Nnn #3 { NV } { T , F , TF }

  }
\__regex_tmp:w \__regex_extract_once:nnN
  \regex_extract_once:nnN \regex_extract_once:NnN
\__regex_tmp:w \__regex_extract_all:nnN
  \regex_extract_all:nnN \regex_extract_all:NnN
\__regex_tmp:w \__regex_replace_once:nnN
  \regex_replace_once:nnN \regex_replace_once:NnN
\__regex_tmp:w \__regex_replace_all:nnN
  \regex_replace_all:nnN \regex_replace_all:NnN
\__regex_tmp:w \__regex_split:nnN \regex_split:nnN \regex_split:NnN
```

(*\regex_extract_once:nnNTF* 以及其它的定义结束。这些函数被记录在第*15*页。)

`\regex_replace_case_once:nN`
`\regex_replace_case_once:nN`*TF*

If the input is bad (odd number of items) then take the false branch. Otherwise, use the same auxiliary as `\regex_replace_once:nnN`, but with more complicated code to build the automaton, and to find what replacement text to use. The `\tl_item:nn` is only expanded once we know the value of `\g__regex_case_int`, namely which case matched.

```
\cs_new_protected:Npn \regex_replace_case_once:nNTF #1#2
  {
    \int_if_odd:nTF { \tl_count:n {#1} }
      {
        \msg_error:nneeee { regex } { case-odd }
          { \token_to_str:N \regex_replace_case_once:nN(TF) } { code }
          { \tl_count:n {#1} } { \tl_to_str:n {#1} }
        \use_ii:nn
      }
      {
        \__regex_replace_once_aux:nnN
          { \__regex_case_build:e { \__regex_tl_odd_items:n {#1} } }
          { \__regex_replacement:e { \tl_item:nn {#1} { 2 * \g__regex_case_int } } }
          #2
        \bool_if:NTF \g__regex_success_bool
      }
  }
\cs_new_protected:Npn \regex_replace_case_once:nN #1#2
  { \regex_replace_case_once:nNTF {#1} {#2} { } { } }
\cs_new_protected:Npn \regex_replace_case_once:nNT #1#2#3
  { \regex_replace_case_once:nNTF {#1} {#2} {#3} { } }
\cs_new_protected:Npn \regex_replace_case_once:nNF #1#2
  { \regex_replace_case_once:nNTF {#1} {#2} { } }
```

(\regex_replace_case_once:nNTF 定义结束。这个函数被记录在第17页。)

\regex_replace_case_all:nN
\regex_replace_case_all:nNTF

If the input is bad (odd number of items) then take the false branch. Otherwise, use the same auxiliary as \regex_replace_all:nnN, but with more complicated code to build the automaton, and to find what replacement text to use.

```
\cs_new_protected:Npn \regex_replace_case_all:nNTF #1#2
  {
    \int_if_odd:nTF { \tl_count:n {#1} }
      {
        \msg_error:nneeee { regex } { case-odd }
          { \token_to_str:N \regex_replace_case_all:nN(TF) } { code }
          { \tl_count:n {#1} } { \tl_to_str:n {#1} }
        \use_ii:nn
      }
      {
        \__regex_replace_all_aux:nnN
          { \__regex_case_build:e { \__regex_tl_odd_items:n {#1} } }
          { \__regex_case_replacement:e { \__regex_tl_even_items:n {#1} } }
          #2
        \bool_if:NTF \g__regex_success_bool
      }
  }
\cs_new_protected:Npn \regex_replace_case_all:nN #1#2
  { \regex_replace_case_all:nNTF {#1} {#2} { } { } }
\cs_new_protected:Npn \regex_replace_case_all:nNT #1#2#3
  { \regex_replace_case_all:nNTF {#1} {#2} {#3} { } }
```

```
\cs_new_protected:Npn \regex_replace_case_all:nNF #1#2
  { \regex_replace_case_all:nNTF {#1} {#2} { } }
```

(*\regex_replace_case_all:nNTF* 定义结束。这个函数被记录在第18页。)

9.7.1 Variables and helpers for user functions

\l__regex_match_count_int

The number of matches found so far is stored in `\l__regex_match_count_int`. This is only used in the `\regex_count:nnN` functions.

```
\int_new:N \l__regex_match_count_int
```

(*\l__regex_match_count_int* 定义结束。)

__regex_begin
__regex_end

Those flags are raised to indicate begin-group or end-group tokens that had to be added when extracting submatches.

```
\flag_new:n { __regex_begin }
\flag_new:n { __regex_end }
```

(*__regex_begin* 和 *__regex_end* 定义结束。)

\l__regex_min_submatch_int
\l__regex_submatch_int
\l__regex_zeroth_submatch_int

The end-points of each submatch are stored in two arrays whose index ⟨*submatch*⟩ ranges from `\l__regex_min_submatch_int` (inclusive) to `\l__regex_submatch_int` (exclusive). Each successful match comes with a 0-th submatch (the full match), and one match for each capturing group: submatches corresponding to the last successful match are labelled starting at `zeroth_submatch`. The entry `\l__regex_zeroth_submatch_int` in `\g__regex_submatch_prev_intarray` holds the position at which that match attempt started: this is used for splitting and replacements.

```
\int_new:N \l__regex_min_submatch_int
\int_new:N \l__regex_submatch_int
\int_new:N \l__regex_zeroth_submatch_int
```

(*\l__regex_min_submatch_int*, *\l__regex_submatch_int*, 和 *\l__regex_zeroth_submatch_int* 定义结束。)

\g__regex_submatch_prev_intarray
\g__regex_submatch_begin_intarray
\g__regex_submatch_end_intarray
\g__regex_submatch_case_intarray

Hold the place where the match attempt begun, the end-points of each submatch, and which regex case the match corresponds to, respectively.

```
\intarray_new:Nn \g__regex_submatch_prev_intarray { 65536 }
\intarray_new:Nn \g__regex_submatch_begin_intarray { 65536 }
\intarray_new:Nn \g__regex_submatch_end_intarray { 65536 }
\intarray_new:Nn \g__regex_submatch_case_intarray { 65536 }
```

(*\g__regex_submatch_prev_intarray* 以及其它的定义结束。)

\g__regex_balance_intarray The first thing we do when matching is to store the balance of begin-group/end-group characters into \g__regex_balance_intarray.

```
\intarray_new:Nn \g__regex_balance_intarray { 65536 }
```

(*\g__regex_balance_intarray* 定义结束。)

\l__regex_added_begin_int
\l__regex_added_end_int

Keep track of the number of left/right braces to add when performing a regex operation such as a replacement.

```
\int_new:N \l__regex_added_begin_int
\int_new:N \l__regex_added_end_int
```

(*\l__regex_added_begin_int* 和 *\l__regex_added_end_int* 定义结束。)

__regex_return: This function triggers either \prg_return_false: or \prg_return_true: as appropriate to whether a match was found or not. It is used by all user conditionals.

```
\cs_new_protected:Npn \__regex_return:
  {
    \if_meaning:w \c_true_bool \g__regex_success_bool
      \prg_return_true:
    \else:
      \prg_return_false:
    \fi:
  }
```

(*__regex_return:* 定义结束。)

__regex_query_set:n
__regex_query_set_aux:nN

To easily extract subsets of the input once we found the positions at which to cut, store the input tokens one by one into successive \toks registers. Also store the brace balance (used to check for overall brace balance) in an array.

```
\cs_new_protected:Npn \__regex_query_set:n #1
  {
    \int_zero:N \l__regex_balance_int
    \int_zero:N \l__regex_curr_pos_int
    \__regex_query_set_aux:nN { } F
    \tl_analysis_map_inline:nn {#1}
      { \__regex_query_set_aux:nN {##1} ##3 }
    \__regex_query_set_aux:nN { } F
    \int_set_eq:NN \l__regex_max_pos_int \l__regex_curr_pos_int
  }
\cs_new_protected:Npn \__regex_query_set_aux:nN #1#2
  {
    \int_incr:N \l__regex_curr_pos_int
    \__regex_toks_set:Nn \l__regex_curr_pos_int {#1}
    \__kernel_intarray_gset:Nnn \g__regex_balance_intarray
      { \l__regex_curr_pos_int } { \l__regex_balance_int }
    \if_case:w "#2 \exp_stop_f:
    \or: \int_incr:N \l__regex_balance_int
    \or: \int_decr:N \l__regex_balance_int
    \fi:
  }
```

(__*regex_query_set:n* 和 __*regex_query_set_aux:nN* 定义结束。)

9.7.2 Matching

__regex_if_match:nn

We don't track submatches, and stop after a single match. Build the NFA with #1, and perform the match on the query #2.

```
\cs_new_protected:Npn \__regex_if_match:nn #1#2
  {
    \group_begin:
      \__regex_disable_submatches:
      \__regex_single_match:
      #1
      \__regex_match:n {#2}
    \group_end:
  }
```

(__*regex_if_match:nn* 定义结束。)

__regex_match_case:nnTF
__regex_match_case_aux:nn

The code would get badly messed up if the number of items in #1 were not even, so we catch this case, then follow the same code as \regex_match:nnTF but using __regex_case_build:n and without returning a result.

```
\cs_new_protected:Npn \__regex_match_case:nnTF #1#2
  {
    \int_if_odd:nTF { \tl_count:n {#1} }
      {
        \msg_error:nneeee { regex } { case-odd }
          { \token_to_str:N \regex_match_case:nn(TF) } { code }
          { \tl_count:n {#1} } { \tl_to_str:n {#1} }
        \use_ii:nn
      }
      {
        \__regex_if_match:nn
          { \__regex_case_build:e { \__regex_tl_odd_items:n {#1} } }
          {#2}
        \bool_if:NTF \g__regex_success_bool
      }
  }
\cs_new:Npn \__regex_match_case_aux:nn #1#2 { \exp_not:n { {#1} } }
```

(__regex_match_case:nnTF 和 __regex_match_case_aux:nn 定义结束。)

__regex_count:nnN Again, we don't care about submatches. Instead of aborting after the first "longest match" is found, we search for multiple matches, incrementing \l__regex_match_count_int every time to record the number of matches. Build the NFA and match. At the end, store the result in the user's variable.

```
\cs_new_protected:Npn \__regex_count:nnN #1#2#3
  {
    \group_begin:
      \__regex_disable_submatches:
      \int_zero:N \l__regex_match_count_int
      \__regex_multi_match:n { \int_incr:N \l__regex_match_count_int }
      #1
      \__regex_match:n {#2}
      \exp_args:NNNo
    \group_end:
    \int_set:Nn #3 { \int_use:N \l__regex_match_count_int }
  }
```

(__regex_count:nnN 定义结束。)

9.7.3 Extracting submatches

__regex_extract_once:nnN
__regex_extract_all:nnN

Match once or multiple times. After each match (or after the only match), extract the submatches using __regex_extract:. At the end, store the sequence containing all the submatches into the user variable #3 after closing the group.

```
\cs_new_protected:Npn \__regex_extract_once:nnN #1#2#3
  {
    \group_begin:
      \__regex_single_match:
      #1
      \__regex_match:n {#2}
      \__regex_extract:
      \__regex_query_set:n {#2}
    \__regex_group_end_extract_seq:N #3
  }
\cs_new_protected:Npn \__regex_extract_all:nnN #1#2#3
```

```
  {
    \group_begin:
      \__regex_multi_match:n { \__regex_extract: }
      #1
      \__regex_match:n {#2}
      \__regex_query_set:n {#2}
    \__regex_group_end_extract_seq:N #3
  }
```

（__regex_extract_once:nnN 和 __regex_extract_all:nnN 定义结束。）

__regex_split:nnN

Splitting at submatches is a bit more tricky. For each match, extract all submatches, and replace the zeroth submatch by the part of the query between the start of the match attempt and the start of the zeroth submatch. This is inhibited if the delimiter matched an empty token list at the start of this match attempt. After the last match, store the last part of the token list, which ranges from the start of the match attempt to the end of the query. This step is inhibited if the last match was empty and at the very end: decrement \l__regex_submatch_int, which controls which matches will be used.

```
\cs_new_protected:Npn \__regex_split:nnN #1#2#3
  {
    \group_begin:
      \__regex_multi_match:n
        {
          \if_int_compare:w
            \l__regex_start_pos_int < \l__regex_success_pos_int
            \__regex_extract:
            \__kernel_intarray_gset:Nnn \g__regex_submatch_prev_intarray
              { \l__regex_zeroth_submatch_int } { 0 }
            \__kernel_intarray_gset:Nnn \g__regex_submatch_end_intarray
              { \l__regex_zeroth_submatch_int }
              {
                \__kernel_intarray_item:Nn \g__regex_submatch_begin_intarray
                  { \l__regex_zeroth_submatch_int }
              }
            \__kernel_intarray_gset:Nnn \g__regex_submatch_begin_intarray
              { \l__regex_zeroth_submatch_int }
              { \l__regex_start_pos_int }
          \fi:
        }
      #1
      \__regex_match:n {#2}
      \__regex_query_set:n {#2}
      \__kernel_intarray_gset:Nnn \g__regex_submatch_prev_intarray
        { \l__regex_submatch_int } { 0 }
      \__kernel_intarray_gset:Nnn \g__regex_submatch_end_intarray
        { \l__regex_submatch_int }
        { \l__regex_max_pos_int }
      \__kernel_intarray_gset:Nnn \g__regex_submatch_begin_intarray
        { \l__regex_submatch_int }
        { \l__regex_start_pos_int }
      \int_incr:N \l__regex_submatch_int
      \if_meaning:w \c_true_bool \l__regex_empty_success_bool
        \if_int_compare:w \l__regex_start_pos_int = \l__regex_max_pos_int
          \int_decr:N \l__regex_submatch_int
        \fi:
      \fi:
    \__regex_group_end_extract_seq:N #3
  }
```

(__*regex*_*split:nnN* 定义结束。)

__regex_group_end_extract_seq:N
__regex_extract_seq:N
__regex_extract_seq:NNn
__regex_extract_seq_loop:Nw

The end-points of submatches are stored as entries of two arrays from `\l__regex_min_submatch_int` to `\l__regex_submatch_int` (exclusive). Extract the relevant ranges into `\g__regex_internal_tl`, separated by `\__regex_tmp:w {}`. We keep track in the two flags `__regex_begin` and `__regex_end` of the number of begin-group or end-group tokens added to make each of these items overall balanced. At this step, `}{` is counted as being balanced (same number of begin-group and end-group tokens). This problem is caught by `\__regex_extract_check:w`, explained later. After complaining about any begin-group or end-group tokens we had to add, we are ready to construct the user's sequence outside the group.

```
\cs_new_protected:Npn \__regex_group_end_extract_seq:N #1
  {
      \flag_clear:n { __regex_begin }
      \flag_clear:n { __regex_end }
      \cs_set_eq:NN \__regex_tmp:w \scan_stop:
      \__kernel_tl_gset:Ne \g__regex_internal_tl
        {
          \int_step_function:nnN { \l__regex_min_submatch_int }
            { \l__regex_submatch_int - 1 } \__regex_extract_seq_aux:n
          \__regex_tmp:w
        }
      \int_set:Nn \l__regex_added_begin_int
```

```
        { \flag_height:n { __regex_begin } }
      \int_set:Nn \l__regex_added_end_int
        { \flag_height:n { __regex_end } }
      \tex_afterassignment:D \__regex_extract_check:w
      \__kernel_tl_gset:Ne \g__regex_internal_tl
        { \g__regex_internal_tl \if_false: { \fi: } }
      \int_compare:nNnT
        { \l__regex_added_begin_int + \l__regex_added_end_int } > 0
        {
          \msg_error:nneee { regex } { result-unbalanced }
            { splitting~or~extracting~submatches }
            { \int_use:N \l__regex_added_begin_int }
            { \int_use:N \l__regex_added_end_int }
        }
    \group_end:
    \__regex_extract_seq:N #1
  }
\cs_gset_protected:Npn \__regex_extract_seq:N #1
  {
    \seq_clear:N #1
    \cs_set_eq:NN \__regex_tmp:w  \__regex_extract_seq_loop:Nw
    \exp_after:wN \__regex_extract_seq:NNn
    \exp_after:wN #1
    \g__regex_internal_tl \use_none:nnn
  }
\cs_new_protected:Npn \__regex_extract_seq:NNn #1#2#3
  { #3 #2 #1 \prg_do_nothing: }
\cs_new_protected:Npn \__regex_extract_seq_loop:Nw #1#2 \__regex_tmp:w #3
  {
    \seq_put_right:No #1 {#2}
    #3 \__regex_extract_seq_loop:Nw #1 \prg_do_nothing:
  }
```

(*__regex_group_end_extract_seq:N* 以及其它的定义结束。)

__regex_extract_seq_aux:n
__regex_extract_seq_aux:ww

The :n auxiliary builds one item of the sequence of submatches. First compute the brace balance of the submatch, then extract the submatch from the query, adding the appropriate braces and raising a flag if the submatch is not balanced.

```
\cs_new:Npn \__regex_extract_seq_aux:n #1
  {
    \__regex_tmp:w { }
    \exp_after:wN \__regex_extract_seq_aux:ww
    \int_value:w \__regex_submatch_balance:n {#1} ; #1;
  }
\cs_new:Npn \__regex_extract_seq_aux:ww #1; #2;
  {
    \if_int_compare:w #1 < \c_zero_int
      \prg_replicate:nn {-#1}
        {
          \flag_raise:n { __regex_begin }
          \exp_not:n { { \if_false: } \fi: }
        }
    \fi:
    \__regex_query_submatch:n {#2}
    \if_int_compare:w #1 > \c_zero_int
      \prg_replicate:nn {#1}
        {
          \flag_raise:n { __regex_end }
          \exp_not:n { \if_false: { \fi: } }
        }
    \fi:
  }
```

(*__regex_extract_seq_aux:n* 和 *__regex_extract_seq_aux:ww* 定义结束。)

__regex_extract_check:w
__regex_extract_check:n
__regex_extract_check_loop:w
__regex_extract_check_end:w

In __regex_group_end_extract_seq:N we had to expand \g__regex_internal_tl to turn \if_false: constructions into actual begin-group and end-group tokens. This is done with a __kernel_tl_gset:Ne assignment, and __regex_extract_check:w is run immediately after this assignment ends, thanks to the \afterassignment primitive. If all of the items were properly balanced (enough begin-group tokens before end-group tokens, so }{ is not) then __regex_extract_check:w is called just before the closing brace of the __kernel_tl_gset:Ne (thanks to our sneaky \if_false: { \fi: } construction), and finds that there is nothing left to expand. If any of the items is unbalanced, the assignment gets ended early by an extra end-group token, and our check finds more tokens needing to be expanded in a new __kernel_tl_gset:Ne assignment. We need to add a begin-group and an end-group tokens to the unbalanced item, namely to the last item found so far, which we reach through a loop.

```
\cs_new_protected:Npn \__regex_extract_check:w
  {
    \exp_after:wN \__regex_extract_check:n
    \exp_after:wN { \if_false: } \fi:
  }
```

```
\cs_new_protected:Npn \__regex_extract_check:n #1
  {
    \tl_if_empty:nF {#1}
      {
        \int_incr:N \l__regex_added_begin_int
        \int_incr:N \l__regex_added_end_int
        \tex_afterassignment:D \__regex_extract_check:w
        \__kernel_tl_gset:Ne \g__regex_internal_tl
          {
            \exp_after:wN \__regex_extract_check_loop:w
            \g__regex_internal_tl
            \__regex_tmp:w \__regex_extract_check_end:w
            #1
          }
      }
  }
\cs_new:Npn \__regex_extract_check_loop:w #1 \__regex_tmp:w #2
  {
    #2
    \exp_not:o {#1}
    \__regex_tmp:w { }
    \__regex_extract_check_loop:w \prg_do_nothing:
  }
```

Arguments of `\__regex_extract_check_end:w` are: `#1` is the part of the item before the extra end-group token; `#2` is junk; `#3` is `\prg_do_nothing:` followed by the not-yet-expanded part of the item after the extra end-group token. In the replacement text, the first brace and the `\if_false: { \fi: }` construction are the added begin-group and end-group tokens (the latter being not-yet expanded, just like `#3`), while the closing brace after `\exp_not:o {#1}` replaces the extra end-group token that had ended the assignment early. In particular this means that the character code of that end-group token is lost.

```
\cs_new:Npn \__regex_extract_check_end:w
    \exp_not:o #1#2 \__regex_extract_check_loop:w #3 \__regex_tmp:w
  {
    { \exp_not:o {#1} }
    #3
    \if_false: { \fi: }
    \__regex_tmp:w
  }
```

(*__regex_extract_check:w* 以及其它的定义结束。)

__regex_extract:
__regex_extract_aux:w

Our task here is to store the list of end-points of submatches, and store them in appropriate array entries, from \l__regex_zeroth_submatch_int upwards. First, we store in \g__regex_submatch_prev_intarray the position at which the match attempt started. We extract the rest from the comma list \l__regex_success_submatches_tl, which starts with entries to be stored in \g__regex_submatch_begin_intarray and continues with entries for \g__regex_submatch_end_intarray.

```
\cs_new_protected:Npn \__regex_extract:
  {
    \if_meaning:w \c_true_bool \g__regex_success_bool
      \int_set_eq:NN \l__regex_zeroth_submatch_int \l__regex_submatch_int
      \prg_replicate:nn \l__regex_capturing_group_int
        {
          \__kernel_intarray_gset:Nnn \g__regex_submatch_prev_intarray
            { \l__regex_submatch_int } { 0 }
          \__kernel_intarray_gset:Nnn \g__regex_submatch_case_intarray
            { \l__regex_submatch_int } { 0 }
          \int_incr:N \l__regex_submatch_int
        }
      \__kernel_intarray_gset:Nnn \g__regex_submatch_prev_intarray
        { \l__regex_zeroth_submatch_int } { \l__regex_start_pos_int }
      \__kernel_intarray_gset:Nnn \g__regex_submatch_case_intarray
        { \l__regex_zeroth_submatch_int } { \g__regex_case_int }
      \int_zero:N \l__regex_internal_a_int
      \exp_after:wN \__regex_extract_aux:w \l__regex_success_submatches_tl
        \prg_break_point: \__regex_use_none_delimit_by_q_recursion_stop:w ,
        \q__regex_recursion_stop
    \fi:
  }
\cs_new_protected:Npn \__regex_extract_aux:w #1 ,
  {
    \prg_break: #1 \prg_break_point:
    \if_int_compare:w \l__regex_internal_a_int < \l__regex_capturing_group_int
      \__kernel_intarray_gset:Nnn \g__regex_submatch_begin_intarray
        { \__regex_int_eval:w \l__regex_zeroth_submatch_int + \l__regex_internal_a_int } {#1
    \else:
      \__kernel_intarray_gset:Nnn \g__regex_submatch_end_intarray
        { \__regex_int_eval:w \l__regex_zeroth_submatch_int + \l__regex_internal_a_int - \l_
    \fi:
    \int_incr:N \l__regex_internal_a_int
    \__regex_extract_aux:w
  }
```

(*__regex_extract:* 和 *__regex_extract_aux:w* 定义结束。)

9.7.4 Replacement

__regex_replace_once:nnN
__regex_replace_once_aux:nnN

Build the NFA and the replacement functions, then find a single match. If the match failed, simply exit the group. Otherwise, we do the replacement. Extract submatches. Compute the brace balance corresponding to replacing this match by the replacement (this depends on submatches). Prepare the replaced token list: the replacement function produces the tokens from the start of the query to the start of the match and the replacement text for this match; we need to add the tokens from the end of the match to the end of the query. Finally, store the result in the user's variable after closing the group: this step involves an additional e-expansion, and checks that braces are balanced in the final result.

```
\cs_new_protected:Npn \__regex_replace_once:nnN #1#2
  { \__regex_replace_once_aux:nnN {#1} { \__regex_replacement:n {#2} } }
\cs_new_protected:Npn \__regex_replace_once_aux:nnN #1#2#3
  {
    \group_begin:
      \__regex_single_match:
      #1
      \exp_args:No \__regex_match:n {#3}
    \bool_if:NTF \g__regex_success_bool
      {
        \__regex_extract:
        \exp_args:No \__regex_query_set:n {#3}
        #2
        \int_set:Nn \l__regex_balance_int
          {
            \__regex_replacement_balance_one_match:n
              { \l__regex_zeroth_submatch_int }
          }
        \__kernel_tl_set:Ne \l__regex_internal_a_tl
          {
            \__regex_replacement_do_one_match:n
              { \l__regex_zeroth_submatch_int }
            \__regex_query_range:nn
              {
                \__kernel_intarray_item:Nn \g__regex_submatch_end_intarray
                  { \l__regex_zeroth_submatch_int }
```

```
       }
       { \l__regex_max_pos_int }
     }
    \__regex_group_end_replace:N #3
   }
   { \group_end: }
 }
```

（__*regex_replace_once:nnN* 和 __*regex_replace_once_aux:nnN* 定义结束。）

__regex_replace_all:nnN Match multiple times, and for every match, extract submatches and additionally store the position at which the match attempt started. The entries from \l__regex_min_submatch_int to \l__regex_submatch_int hold information about submatches of every match in order; each match corresponds to \l__regex_capturing_group_int consecutive entries. Compute the brace balance corresponding to doing all the replacements: this is the sum of brace balances for replacing each match. Join together the replacement texts for each match (including the part of the query before the match), and the end of the query.

```
\cs_new_protected:Npn \__regex_replace_all:nnN #1#2
 { \__regex_replace_all_aux:nnN {#1} { \__regex_replacement:n {#2} } }
\cs_new_protected:Npn \__regex_replace_all_aux:nnN #1#2#3
 {
  \group_begin:
   \__regex_multi_match:n { \__regex_extract: }
   #1
   \exp_args:No \__regex_match:n {#3}
   \exp_args:No \__regex_query_set:n {#3}
   #2
   \int_set:Nn \l__regex_balance_int
    {
     0
     \int_step_function:nnnN
      { \l__regex_min_submatch_int }
      \l__regex_capturing_group_int
      { \l__regex_submatch_int - 1 }
      \__regex_replacement_balance_one_match:n
    }
   \__kernel_tl_set:Ne \l__regex_internal_a_tl
    {
     \int_step_function:nnnN
      { \l__regex_min_submatch_int }
      \l__regex_capturing_group_int
```

```
            { \l__regex_submatch_int - 1 }
            \__regex_replacement_do_one_match:n
          \__regex_query_range:nn
            \l__regex_start_pos_int \l__regex_max_pos_int
        }
    \__regex_group_end_replace:N #3
  }
```

(__*regex_replace_all:nnN* 定义结束。)

__regex_group_end_replace:N
__regex_group_end_replace_try:
__regex_group_end_replace_check:w
__regex_group_end_replace_check:n

At this stage `\l__regex_internal_a_tl` (e-expands to the desired result). Guess from `\l__regex_balance_int` the number of braces to add before or after the result then try expanding. The simplest case is when `\l__regex_internal_a_tl` together with the braces we insert via `\prg_replicate:nn` give a balanced result, and the assignment ends at the `\if_false: { \fi: }` construction: then `\__regex_group_end_replace_check:w` sees that there is no material left and we successfully found the result. The harder case is that expanding `\l__regex_internal_a_tl` may produce extra closing braces and end the assignment early. Then we grab the remaining code using; importantly, what follows has not yet been expanded so that `\__regex_group_end_replace_check:n` grabs everything until the last brace in `\__regex_group_end_replace_try:`, letting us try again with an extra surrounding pair of braces.

```
\cs_new_protected:Npn \__regex_group_end_replace:N #1
  {
    \int_set:Nn \l__regex_added_begin_int
      { \int_max:nn { - \l__regex_balance_int } { 0 } }
    \int_set:Nn \l__regex_added_end_int
      { \int_max:nn { \l__regex_balance_int } { 0 } }
    \__regex_group_end_replace_try:
    \int_compare:nNnT { \l__regex_added_begin_int + \l__regex_added_end_int } > 0
      {
        \msg_error:nneee { regex } { result-unbalanced }
          { replacing } { \int_use:N \l__regex_added_begin_int }
          { \int_use:N \l__regex_added_end_int }
      }
    \group_end:
    \tl_set_eq:NN #1 \g__regex_internal_tl
  }
\cs_new_protected:Npn \__regex_group_end_replace_try:
  {
    \tex_afterassignment:D \__regex_group_end_replace_check:w
    \__kernel_tl_gset:Ne \g__regex_internal_tl
      {
        \prg_replicate:nn { \l__regex_added_begin_int } { { \if_false: } \fi: }
        \l__regex_internal_a_tl
        \prg_replicate:nn { \l__regex_added_end_int } { \if_false: { \fi: } }
        \if_false: { \fi: }
      }
  }
\cs_new_protected:Npn \__regex_group_end_replace_check:w
  {
    \exp_after:wN \__regex_group_end_replace_check:n
    \exp_after:wN { \if_false: } \fi:
  }
\cs_new_protected:Npn \__regex_group_end_replace_check:n #1
  {
    \tl_if_empty:nF {#1}
      {
        \int_incr:N \l__regex_added_begin_int
        \int_incr:N \l__regex_added_end_int
        \__regex_group_end_replace_try:
      }
  }
```

(*__regex_group_end_replace:N 以及其它的定义结束。*)

9.7.5 Peeking ahead

\l__regex_peek_true_tl
\l__regex_peek_false_tl

True/false code arguments of \peek_regex:nTF or similar.

```
\tl_new:N \l__regex_peek_true_tl
\tl_new:N \l__regex_peek_false_tl
```

(*\l__regex_peek_true_tl 和 \l__regex_peek_false_tl 定义结束。*)

\l__regex_replacement_tl

When peeking in \peek_regex_replace_once:nnTF we need to store the replacement text.

```
\tl_new:N \l__regex_replacement_tl
```

(*\l__regex_replacement_tl 定义结束。*)

\l__regex_input_tl
__regex_input_item:n

Stores each token found as __regex_input_item:n {⟨*tokens*⟩}, where the ⟨*tokens*⟩ o-expand to the token found, as for \tl_analysis_map_inline:nn.

```
\tl_new:N \l__regex_input_tl
\cs_new_eq:NN \__regex_input_item:n ?
```

(\l__regex_input_tl 和 __regex_input_item:n 定义结束。)

\peek_regex:n*TF*
\peek_regex:N*TF*
\peek_regex_remove_once:n*TF*
\peek_regex_remove_once:N*TF*

The T and F functions just call the corresponding TF function. The four TF functions differ along two axes: whether to remove the token or not, distinguished by using __regex_peek_end: or __regex_peek_remove_end:n (the latter case needs an argument, as we will see), and whether the regex has to be compiled or is already in an N-type variable, distinguished by calling __regex_build_aux:Nn or __regex_build_aux:NN. The first argument of these functions is \c_false_bool to indicate that there should be no implicit insertion of a wildcard at the start of the pattern: otherwise the code would keep looking further into the input stream until matching the regex.

```
\cs_new_protected:Npn \peek_regex:nTF #1
  {
    \__regex_peek:nnTF
      { \__regex_build_aux:Nn \c_false_bool {#1} }
      { \__regex_peek_end: }
  }
\cs_new_protected:Npn \peek_regex:nT #1#2
  { \peek_regex:nTF {#1} {#2} { } }
\cs_new_protected:Npn \peek_regex:nF #1 { \peek_regex:nTF {#1} { } }
\cs_new_protected:Npn \peek_regex:NTF #1
  {
    \__regex_peek:nnTF
      { \__regex_build_aux:NN \c_false_bool #1 }
      { \__regex_peek_end: }
  }
\cs_new_protected:Npn \peek_regex:NT #1#2
  { \peek_regex:NTF #1 {#2} { } }
\cs_new_protected:Npn \peek_regex:NF #1 { \peek_regex:NTF {#1} { } }
\cs_new_protected:Npn \peek_regex_remove_once:nTF #1
  {
    \__regex_peek:nnTF
      { \__regex_build_aux:Nn \c_false_bool {#1} }
      { \__regex_peek_remove_end:n {##1} }
  }
\cs_new_protected:Npn \peek_regex_remove_once:nT #1#2
  { \peek_regex_remove_once:nTF {#1} {#2} { } }
\cs_new_protected:Npn \peek_regex_remove_once:nF #1
  { \peek_regex_remove_once:nTF {#1} { } }
\cs_new_protected:Npn \peek_regex_remove_once:NTF #1
  {
    \__regex_peek:nnTF
      { \__regex_build_aux:NN \c_false_bool #1 }
      { \__regex_peek_remove_end:n {##1} }
  }
\cs_new_protected:Npn \peek_regex_remove_once:NT #1#2
  { \peek_regex_remove_once:NTF #1 {#2} { } }
\cs_new_protected:Npn \peek_regex_remove_once:NF #1
  { \peek_regex_remove_once:NTF #1 { } }
```

(\peek_regex:nTF 以及其它的定义结束。这些函数被记录在第??页。)

__regex_peek:nnTF
__regex_peek_aux:nnTF

Store the user's true/false codes (plus \group_end:) into two token lists. Then build the automaton with #1, without submatch tracking, and aiming for a single match. Then start matching by setting up a few variables like for any regex matching like \regex_match:nnTF, with the addition of \l__regex_input_tl that keeps track of the tokens seen, to reinsert them at the end. Instead of \tl_analysis_map_inline:nn on the input, we call \peek_analysis_map_inline:n to go through tokens in the input stream. Since __regex_match_one_token:nnN calls __regex_maplike_break: we need to catch that and break the \peek_analysis_map_inline:n loop instead.

```
\cs_new_protected:Npn \__regex_peek:nnTF #1
  {
    \__regex_peek_aux:nnTF
      {
        \__regex_disable_submatches:
        #1
      }
  }
\cs_new_protected:Npn \__regex_peek_aux:nnTF #1#2#3#4
  {
    \group_begin:
      \tl_set:Nn \l__regex_peek_true_tl { \group_end: #3 }
      \tl_set:Nn \l__regex_peek_false_tl { \group_end: #4 }
      \__regex_single_match:
      #1
      \__regex_match_init:
      \tl_build_begin:N \l__regex_input_tl
      \__regex_match_once_init:
      \peek_analysis_map_inline:n
        {
          \tl_build_put_right:Nn \l__regex_input_tl
```

```
            { \__regex_input_item:n {##1} }
          \__regex_match_one_token:nnN {##1} {##2} ##3
          \use_none:nnn
          \prg_break_point:Nn \__regex_maplike_break:
            { \peek_analysis_map_break:n {#2} }
        }
  }
```

(__regex_peek:nnTF 和 __regex_peek_aux:nnTF 定义结束。)

__regex_peek_end:
__regex_peek_remove_end:n

Once the regex matches (or permanently fails to match) we call __regex_peek_end:, or __regex_peek_remove_end:n with argument the last token seen. For \peek_regex:nTF we reinsert tokens seen by calling __regex_peek_reinsert:N regardless of the result of the match. For \peek_regex_remove_once:nTF we reinsert the tokens seen only if the match failed; otherwise we just reinsert the tokens #1, with one expansion. To be more precise, #1 consists of tokens that o-expand and e-expand to the last token seen, for example it is \exp_not:N ⟨*cs*⟩ for a control sequence. This means that just doing \exp_after:wN \l__regex_peek_true_tl #1 would be unsafe because the expansion of ⟨*cs*⟩ would be suppressed.

```
\cs_new_protected:Npn \__regex_peek_end:
  {
    \bool_if:NTF \g__regex_success_bool
      { \__regex_peek_reinsert:N \l__regex_peek_true_tl }
      { \__regex_peek_reinsert:N \l__regex_peek_false_tl }
  }
\cs_new_protected:Npn \__regex_peek_remove_end:n #1
  {
    \bool_if:NTF \g__regex_success_bool
      { \exp_args:NNo \use:nn \l__regex_peek_true_tl {#1} }
      { \__regex_peek_reinsert:N \l__regex_peek_false_tl }
  }
```

(__regex_peek_end: 和 __regex_peek_remove_end:n 定义结束。)

__regex_peek_reinsert:N
__regex_reinsert_item:n

Insert the true/false code #1, followed by the tokens found, which were stored in \l__regex_input_tl. For this, loop through that token list using __regex_reinsert_item:n, which expands #1 once to get a single token, and jumps over it to expand what follows, with suitable \exp:w and \exp_end:. We cannot just use \use:e on the whole token list because the result may be unbalanced, which would stop the primitive prematurely, or let it continue beyond where we would like.

```
\cs_new_protected:Npn \__regex_peek_reinsert:N #1
```

```
  {
    \tl_build_end:N \l__regex_input_tl
    \cs_set_eq:NN \__regex_input_item:n \__regex_reinsert_item:n
    \exp_after:wN #1 \exp:w \l__regex_input_tl \exp_end:
  }
\cs_new_protected:Npn \__regex_reinsert_item:n #1
  {
    \exp_after:wN \exp_after:wN
    \exp_after:wN \exp_end:
    \exp_after:wN \exp_after:wN
    #1
    \exp:w
  }
```

(*__regex_peek_reinsert:N* 和 *__regex_reinsert_item:n* 定义结束。)

\peek_regex_replace_once:nn
\peek_regex_replace_once:nn*TF*
\peek_regex_replace_once:Nn
\peek_regex_replace_once:Nn*TF*

Similar to `\peek_regex:nTF` above.

```
\cs_new_protected:Npn \peek_regex_replace_once:nnTF #1
  { \__regex_peek_replace:nnTF { \__regex_build_aux:Nn \c_false_bool {#1} } }
\cs_new_protected:Npn \peek_regex_replace_once:nnT #1#2#3
  { \peek_regex_replace_once:nnTF {#1} {#2} {#3} { } }
\cs_new_protected:Npn \peek_regex_replace_once:nnF #1#2
  { \peek_regex_replace_once:nnTF {#1} {#2} { } }
\cs_new_protected:Npn \peek_regex_replace_once:nn #1#2
  { \peek_regex_replace_once:nnTF {#1} {#2} { } { } }
\cs_new_protected:Npn \peek_regex_replace_once:NnTF #1
  { \__regex_peek_replace:nnTF { \__regex_build_aux:NN \c_false_bool #1 } }
\cs_new_protected:Npn \peek_regex_replace_once:NnT #1#2#3
  { \peek_regex_replace_once:NnTF #1 {#2} {#3} { } }
\cs_new_protected:Npn \peek_regex_replace_once:NnF #1#2
  { \peek_regex_replace_once:NnTF #1 {#2} { } }
\cs_new_protected:Npn \peek_regex_replace_once:Nn #1#2
  { \peek_regex_replace_once:NnTF #1 {#2} { } { } }
```

(*\peek_regex_replace_once:nnTF* 和 *\peek_regex_replace_once:NnTF* 定义结束。这些函数被记录在第**??**页。)

__regex_peek_replace:nnTF

Same as `\__regex_peek:nnTF` (used for `\peek_regex:nTF` above), but without disabling submatches, and with a different end. The replacement text `#2` is stored, to be analyzed later.

```
\cs_new_protected:Npn \__regex_peek_replace:nnTF #1#2
  {
    \tl_set:Nn \l__regex_replacement_tl {#2}
    \__regex_peek_aux:nnTF {#1} { \__regex_peek_replace_end: }
  }
```

(__*regex_peek_replace:nnTF* 定义结束。)

__regex_peek_replace_end: If the match failed `\__regex_peek_reinsert:N` reinserts the tokens found. Otherwise, finish storing the submatch information using `\__regex_extract:`, and store the input into `\toks`. Redefine a few auxiliaries to change slightly their expansion behaviour as explained below. Analyse the replacement text with `\__regex_replacement:n`, which as usual defines `\__regex_replacement_do_one_match:n` to insert the tokens from the start of the match attempt to the beginning of the match, followed by the replacement text. The `\use:e` expands for instance the trailing `\__regex_query_range:nn` down to a sequence of `\__regex_reinsert_item:n` `{`⟨*tokens*⟩`}` where ⟨*tokens*⟩ `o`-expand to a single token that we want to insert. After `e`-expansion, `\use:e` does `\use:n`, so we have `\exp_after:wN \l__regex_peek_true_tl \exp:w … \exp_end:`. This is set up such as to obtain `\l__regex_peek_true_tl` followed by the replaced tokens (possibly unbalanced) in the input stream.

```
\cs_new_protected:Npn \__regex_peek_replace_end:
  {
    \bool_if:NTF \g__regex_success_bool
      {
        \__regex_extract:
        \__regex_query_set_from_input_tl:
        \cs_set_eq:NN \__regex_replacement_put:n \__regex_peek_replacement_put:n
        \cs_set_eq:NN \__regex_replacement_put_submatch_aux:n
          \__regex_peek_replacement_put_submatch_aux:n
        \cs_set_eq:NN \__regex_input_item:n \__regex_reinsert_item:n
        \cs_set_eq:NN \__regex_replacement_exp_not:N \__regex_peek_replacement_token:n
        \cs_set_eq:NN \__regex_replacement_exp_not:V \__regex_peek_replacement_var:N
        \exp_args:No \__regex_replacement:n { \l__regex_replacement_tl }
        \use:e
          {
            \exp_not:n { \exp_after:wN \l__regex_peek_true_tl \exp:w }
            \__regex_replacement_do_one_match:n
              { \l__regex_zeroth_submatch_int }
            \__regex_query_range:nn
              {
                \__kernel_intarray_item:Nn \g__regex_submatch_end_intarray
                  { \l__regex_zeroth_submatch_int }
              }
              { \l__regex_max_pos_int }
            \exp_end:
          }
      }
      { \__regex_peek_reinsert:N \l__regex_peek_false_tl }
  }
```

(__*regex_peek_replace_end:* 定义结束。)

__regex_query_set_from_input_tl:
__regex_query_set_item:n

The input was stored into `\l__regex_input_tl` as successive items `\__regex_input_item:n` {⟨*tokens*⟩}. Store that in successive `\toks`. It's not clear whether the empty entries before and after are both useful.

```
\cs_new_protected:Npn \__regex_query_set_from_input_tl:
  {
    \tl_build_end:N \l__regex_input_tl
    \int_zero:N \l__regex_curr_pos_int
    \cs_set_eq:NN \__regex_input_item:n \__regex_query_set_item:n
    \__regex_query_set_item:n { }
    \l__regex_input_tl
    \__regex_query_set_item:n { }
    \int_set_eq:NN \l__regex_max_pos_int \l__regex_curr_pos_int
  }
\cs_new_protected:Npn \__regex_query_set_item:n #1
  {
    \int_incr:N \l__regex_curr_pos_int
    \__regex_toks_set:Nn \l__regex_curr_pos_int { \__regex_input_item:n {#1} }
  }
```

(__*regex_query_set_from_input_tl:* 和 __*regex_query_set_item:n* 定义结束。)

__regex_peek_replacement_put:n

While building the replacement function `\__regex_replacement_do_one_match:n`, we often want to put simple material, given as `#1`, whose `e`-expansion `o`-expands to a single token. Normally we can just add the token to `\l__regex_build_tl`, but for `\peek_regex_replace_once:nnTF` we eventually want to do some strange expansion that is basically using `\exp_after:wN` to jump through numerous tokens (we cannot use `e`-expansion like for `\regex_replace_once:nnNTF` because it is ok for the result to be unbalanced since we insert it in the input stream rather than storing it. When within a csname we don't do any such shenanigan because `\cs:w` … `\cs_end:` does all the expansion we need.

```
\cs_new_protected:Npn \__regex_peek_replacement_put:n #1
  {
    \if_case:w \l__regex_replacement_csnames_int
      \tl_build_put_right:Nn \l__regex_build_tl
```

```
        { \exp_not:N \__regex_reinsert_item:n {#1} }
    \else:
      \tl_build_put_right:Nn \l__regex_build_tl {#1}
    \fi:
  }
```

(__*regex_peek_replacement_put:n* 定义结束。)

__regex_peek_replacement_token:n

When hit with `\exp:w`, `\__regex_peek_replacement_token:n {`⟨*token*⟩`}` stops `\exp_end:` and does `\exp_after:wN` ⟨*token*⟩ `\exp:w` to continue expansion after it.

```
\cs_new_protected:Npn \__regex_peek_replacement_token:n #1
  { \exp_after:wN \exp_end: \exp_after:wN #1 \exp:w }
```

(__*regex_peek_replacement_token:n* 定义结束。)

__regex_peek_replacement_put_submatch_aux:n

While analyzing the replacement we also have to insert submatches found in the query. Since query items `\__regex_input_item:n {`⟨*tokens*⟩`}` expand correctly only when surrounded by `\exp:w` … `\exp_end:`, and since these expansion controls are not there within csnames (because `\cs:w` … `\cs_end:` make them unnecessary in most cases), we have to put `\exp:w` and `\exp_end:` by hand here.

```
\cs_new_protected:Npn \__regex_peek_replacement_put_submatch_aux:n #1
  {
    \if_case:w \l__regex_replacement_csnames_int
      \tl_build_put_right:Nn \l__regex_build_tl
        { \__regex_query_submatch:n { \int_eval:n { #1 + ##1 } } }
    \else:
      \tl_build_put_right:Nn \l__regex_build_tl
        { \exp:w \__regex_query_submatch:n { \int_eval:n { #1 + ##1 } } \exp_end: }
    \fi:
  }
```

(__*regex_peek_replacement_put_submatch_aux:n* 定义结束。)

__regex_peek_replacement_var:N

This is used for `\u` outside csnames. It makes sure to continue expansion with `\exp:w` before expanding the variable `#1` and stopping the `\exp:w` that precedes.

```
\cs_new_protected:Npn \__regex_peek_replacement_var:N #1
  {
    \exp_after:wN \exp_last_unbraced:NV
    \exp_after:wN \exp_end:
    \exp_after:wN #1
    \exp:w
  }
```

(__*regex_peek_replacement_var:N* 定义结束。)

9.8 Messages

Messages for the preparsing phase.

```
\use:e
  {
    \msg_new:nnn { regex } { trailing-backslash }
      { Trailing~'\iow_char:N\\'~in~regex~or~replacement. }
    \msg_new:nnn { regex } { x-missing-rbrace }
      {
        Missing~brace~'\iow_char:N\}'~in~regex~
        '...\iow_char:N\\x\iow_char:N\{...##1'.
      }
    \msg_new:nnn { regex } { x-overflow }
      {
        Character~code~##1~too~large~in~
        \iow_char:N\\x\iow_char:N\{##2\iow_char:N\}~regex.
      }
  }
```

Invalid quantifier.

```
\msg_new:nnnn { regex } { invalid-quantifier }
  { Braced~quantifier~'#1'~may~not~be~followed~by~'#2'. }
  {
    The~character~'#2'~is~invalid~in~the~braced~quantifier~'#1'.~
    The~only~valid~quantifiers~are~'*',~'?',~'+',~'{<int>}',~
    '{<min>,}'~and~'{<min>,<max>}',~optionally~followed~by~'?'.
  }
```

Messages for missing or extra closing brackets and parentheses, with some fancy singular/plural handling for the case of parentheses.

```
\msg_new:nnnn { regex } { missing-rbrack }
  { Missing~right~bracket~inserted~in~regular~expression. }
  {
    LaTeX~was~given~a~regular~expression~where~a~character~class~
    was~started~with~'[',~but~the~matching~']'~is~missing.
  }
\msg_new:nnnn { regex } { missing-rparen }
  {
    Missing~right~
    \int_compare:nTF { #1 = 1 } { parenthesis } { parentheses } ~
    inserted~in~regular~expression.
  }
  {
    LaTeX~was~given~a~regular~expression~with~\int_eval:n {#1} ~
    more~left~parentheses~than~right~parentheses.
  }
\msg_new:nnnn { regex } { extra-rparen }
  { Extra~right~parenthesis~ignored~in~regular~expression. }
  {
    LaTeX~came~across~a~closing~parenthesis~when~no~submatch~group~
    was~open.~The~parenthesis~will~be~ignored.
  }
```

Some escaped alphanumerics are not allowed everywhere.

```
\msg_new:nnnn { regex } { bad-escape }
  {
    Invalid~escape~'\iow_char:N\\#1'~
    \__regex_if_in_cs:TF { within~a~control~sequence. }
      {
        \__regex_if_in_class:TF
          { in~a~character~class. }
          { following~a~category~test. }
      }
  }
  {
    The~escape~sequence~'\iow_char:N\\#1'~may~not~appear~
    \__regex_if_in_cs:TF
      {
        within~a~control~sequence~test~introduced~by~
        '\iow_char:N\\c\iow_char:N\{'.
      }
      {
        \__regex_if_in_class:TF
          { within~a~character~class~ }
          { following~a~category~test~such~as~'\iow_char:N\\cL'~ }
        because~it~does~not~match~exactly~one~character.
      }
  }
```

Range errors.

```
\msg_new:nnnn { regex } { range-missing-end }
  { Invalid~end-point~for~range~'#1-#2'~in~character~class. }
  {
    The~end-point~'#2'~of~the~range~'#1-#2'~may~not~serve~as~an~
    end-point~for~a~range:~alphanumeric~characters~should~not~be~
    escaped,~and~non-alphanumeric~characters~should~be~escaped.
  }
\msg_new:nnnn { regex } { range-backwards }
  { Range~'[#1-#2]'~out~of~order~in~character~class. }
  {
    In~ranges~of~characters~'[x-y]'~appearing~in~character~classes,~
    the~first~character~code~must~not~be~larger~than~the~second.~
    Here,~'#1'~has~character~code~\int_eval:n {`#1},~while~
    '#2'~has~character~code~\int_eval:n {`#2}.
  }
```

Errors related to \c and \u.

```
\msg_new:nnnn { regex } { c-bad-mode }
  { Invalid~nested~'\iow_char:N\\c'~escape~in~regular~expression. }
  {
    The~'\iow_char:N\\c'~escape~cannot~be~used~within~
    a~control~sequence~test~'\iow_char:N\\c{...}'~
    nor~another~category~test.~
    To~combine~several~category~tests,~use~'\iow_char:N\\c[...]'.
  }
\msg_new:nnnn { regex } { c-C-invalid }
  { '\iow_char:N\\cC'~should~be~followed~by~'.'~or~'(',~not~'#1'. }
  {
    The~'\iow_char:N\\cC'~construction~restricts~the~next~item~to~be~a~
    control~sequence~or~the~next~group~to~be~made~of~control~sequences.~
    It~only~makes~sense~to~follow~it~by~'.'~or~by~a~group.
  }
\msg_new:nnnn { regex } { cu-lbrace }
  { Left~braces~must~be~escaped~in~'\iow_char:N\\#1{...}'. }
  {
    Constructions~such~as~'\iow_char:N\\#1{...\iow_char:N\{...}'~are~
    not~allowed~and~should~be~replaced~by~
    '\iow_char:N\\#1{...\token_to_str:N\{...}'.
  }
\msg_new:nnnn { regex } { c-lparen-in-class }
  { Catcode~test~cannot~apply~to~group~in~character~class }
  {
    Construction~such~as~'\iow_char:N\\cL(abc)'~are~not~allowed~inside~a~
    class~'[...]'~because~classes~do~not~match~multiple~characters~at~once.
  }
\msg_new:nnnn { regex } { c-missing-rbrace }
  { Missing~right~brace~inserted~for~'\iow_char:N\\c'~escape. }
  {
    LaTeX~was~given~a~regular~expression~where~a~
    '\iow_char:N\\c\iow_char:N\{...'~construction~was~not~ended~
    with~a~closing~brace~'\iow_char:N\}'.
  }
\msg_new:nnnn { regex } { c-missing-rbrack }
  { Missing~right~bracket~inserted~for~'\iow_char:N\\c'~escape. }
  {
    A~construction~'\iow_char:N\\c[...'~appears~in~a~
    regular~expression,~but~the~closing~']'~is~not~present.
  }
\msg_new:nnnn { regex } { c-missing-category }
  { Invalid~character~'#1'~following~'\iow_char:N\\c'~escape. }
  {
    In~regular~expressions,~the~'\iow_char:N\\c'~escape~sequence~
    may~only~be~followed~by~a~left~brace,~a~left~bracket,~or~a~
    capital~letter~representing~a~character~category,~namely~
    one~of~'ABCDELMOPSTU'.
  }
\msg_new:nnnn { regex } { c-trailing }
  { Trailing~category~code~escape~'\iow_char:N\\c'... }
  {
    A~regular~expression~ends~with~'\iow_char:N\\c'~followed~
    by~a~letter.~It~will~be~ignored.
  }
\msg_new:nnnn { regex } { u-missing-lbrace }
  { Missing~left~brace~following~'\iow_char:N\\u'~escape. }
  {
    The~'\iow_char:N\\u'~escape~sequence~must~be~followed~by~
    a~brace~group~with~the~name~of~the~variable~to~use.
  }
\msg_new:nnnn { regex } { u-missing-rbrace }
  { Missing~right~brace~inserted~for~'\iow_char:N\\u'~escape. }
  {
    LaTeX~
    \str_if_eq:eeTF { } {#2}
      { reached~the~end~of~the~string~ }
      { encountered~an~escaped~alphanumeric~character '\iow_char:N\\#2'~ }
    when~parsing~the~argument~of~an~
    '\iow_char:N\\u\iow_char:N\{...\}'~escape.
  }
```

Errors when encountering the POSIX syntax [:...:].

```
\msg_new:nnnn { regex } { posix-unsupported }
  { POSIX~collating~element~'[#1 ~ #1]'~not~supported. }
  {
    The~'[.foo.]'~and~'[=bar=]'~syntaxes~have~a~special~meaning~
    in~POSIX~regular~expressions.~This~is~not~supported~by~LaTeX.~
    Maybe~you~forgot~to~escape~a~left~bracket~in~a~character~class?
  }
\msg_new:nnnn { regex } { posix-unknown }
  { POSIX~class~'[:#1:]'~unknown. }
  {
    '[:#1:]'~is~not~among~the~known~POSIX~classes~
    '[:alnum:]',~'[:alpha:]',~'[:ascii:]',~'[:blank:]',~
    '[:cntrl:]',~'[:digit:]',~'[:graph:]',~'[:lower:]',~
    '[:print:]',~'[:punct:]',~'[:space:]',~'[:upper:]',~
    '[:word:]',~and~'[:xdigit:]'.
  }
\msg_new:nnnn { regex } { posix-missing-close }
  { Missing~closing~':]'~for~POSIX~class. }
  { The~POSIX~syntax~'#1'~must~be~followed~by~':]',~not~'#2'. }
```

In various cases, the result of a l3regex operation can leave us with an unbalanced token list, which we must re-balance by adding begin-group or end-group character tokens.

```
\msg_new:nnnn { regex } { result-unbalanced }
  { Missing~brace~inserted~when~#1. }
  {
    LaTeX~was~asked~to~do~some~regular~expression~operation,~
    and~the~resulting~token~list~would~not~have~the~same~number~
    of~begin-group~and~end-group~tokens.~Braces~were~inserted:~
    #2~left,~#3~right.
  }
```

Error message for unknown options.

```
\msg_new:nnnn { regex } { unknown-option }
  { Unknown~option~'#1'~for~regular~expressions. }
  {
    The~only~available~option~is~'case-insensitive',~toggled~by~
    '(?i)'~and~'(?-i)'.
  }
\msg_new:nnnn { regex } { special-group-unknown }
  { Unknown~special~group~'#1~...'~in~a~regular~expression. }
  {
    The~only~valid~constructions~starting~with~'(?'~are~
    '(?:~...~)',~'(?|~...~)',~'(?i)',~and~'(?-i)'.
  }
```

Errors in the replacement text.

```
\msg_new:nnnn { regex } { replacement-c }
  { Misused~'\iow_char:N\\c'~command~in~a~replacement~text. }
  {
    In~a~replacement~text,~the~'\iow_char:N\\c'~escape~sequence~
    can~be~followed~by~one~of~the~letters~'ABCDELMOPSTU'~
    or~a~brace~group,~not~by~'#1'.
  }
\msg_new:nnnn { regex } { replacement-u }
  { Misused~'\iow_char:N\\u'~command~in~a~replacement~text. }
  {
    In~a~replacement~text,~the~'\iow_char:N\\u'~escape~sequence~
    must~be~~followed~by~a~brace~group~holding~the~name~of~the~
    variable~to~use.
  }
\msg_new:nnnn { regex } { replacement-g }
  {
    Missing~brace~for~the~'\iow_char:N\\g'~construction~
    in~a~replacement~text.
  }
  {
    In~the~replacement~text~for~a~regular~expression~search,~
    submatches~are~represented~either~as~'\iow_char:N \\g{dd..d}',~
    or~'\\d',~where~'d'~are~single~digits.~Here,~a~brace~is~missing.
  }
\msg_new:nnnn { regex } { replacement-catcode-end }
  {
    Missing~character~for~the~'\iow_char:N\\c<category><character>'~
    construction~in~a~replacement~text.
  }
  {
    In~a~replacement~text,~the~'\iow_char:N\\c'~escape~sequence~
    can~be~followed~by~one~of~the~letters~'ABCDELMOPSTU'~representing~
    the~character~category.~Then,~a~character~must~follow.~LaTeX~
    reached~the~end~of~the~replacement~when~looking~for~that.
  }
\msg_new:nnnn { regex } { replacement-catcode-escaped }
  {
    Escaped~letter~or~digit~after~category~code~in~replacement~text.
  }
  {
    In~a~replacement~text,~the~'\iow_char:N\\c'~escape~sequence~
    can~be~followed~by~one~of~the~letters~'ABCDELMOPSTU'~representing~
    the~character~category.~Then,~a~character~must~follow,~not~
    '\iow_char:N\\#2'.
  }
\msg_new:nnnn { regex } { replacement-catcode-in-cs }
  {
    Category~code~'\iow_char:N\\c#1#3'~ignored~inside~
    '\iow_char:N\\c\{...\}'~in~a~replacement~text.
  }
  {
    In~a~replacement~text,~the~category~codes~of~the~argument~of~
    '\iow_char:N\\c\{...\}'~are~ignored~when~building~the~control~
    sequence~name.
  }
\msg_new:nnnn { regex } { replacement-null-space }
  { TeX~cannot~build~a~space~token~with~character~code~0. }
  {
    You~asked~for~a~character~token~with~category~space,~
    and~character~code~0,~for~instance~through~
    '\iow_char:N\\cS\iow_char:N\\x00'.~
    This~specific~case~is~impossible~and~will~be~replaced~
    by~a~normal~space.
  }
\msg_new:nnnn { regex } { replacement-missing-rbrace }
  { Missing~right~brace~inserted~in~replacement~text. }
  {
    There~ \int_compare:nTF { #1 = 1 } { was } { were } ~ #1~
    missing~right~\int_compare:nTF { #1 = 1 } { brace } { braces } .
  }
\msg_new:nnnn { regex } { replacement-missing-rparen }
  { Missing~right~parenthesis~inserted~in~replacement~text. }
  {
    There~ \int_compare:nTF { #1 = 1 } { was } { were } ~ #1~
    missing~right~
    \int_compare:nTF { #1 = 1 } { parenthesis } { parentheses } .
  }
\msg_new:nnn { regex } { submatch-too-big }
  { Submatch~#1~used~but~regex~only~has~#2~group(s) }
```

Some escaped alphanumerics are not allowed everywhere.

```
\msg_new:nnnn { regex } { backwards-quantifier }
```

```
  { Quantifer~"{#1,#2}"~is~backwards. }
  { The~values~given~in~a~quantifier~must~be~in~order. }
```

Used in user commands, and when showing a regex.

```
\msg_new:nnnn { regex } { case-odd }
  { #1~with~odd~number~of~items }
  {
    There~must~be~a~#2~part~for~each~regex:~
    found~odd~number~of~items~(#3)~in\\
    \iow_indent:n {#4}
  }
\msg_new:nnn { regex } { show }
  {
    >~Compiled~regex~
    \tl_if_empty:nTF {#1} { variable~ #2 } { {#1} } :
    #3
  }
\prop_gput:Nnn \g_msg_module_name_prop { regex } { LaTeX }
\prop_gput:Nnn \g_msg_module_type_prop { regex } { }
```

__regex_msg_repeated:nnN

This is not technically a message, but seems related enough to go there. The arguments are: #1 is the minimum number of repetitions; #2 is the number of allowed extra repetitions (−1 for infinite number), and #3 tells us about lazyness.

```
\cs_new:Npn \__regex_msg_repeated:nnN #1#2#3
  {
    \str_if_eq:eeF { #1 #2 } { 1 0 }
      {
        , ~ repeated ~
        \int_case:nnF {#2}
          {
            { -1 } { #1~or~more~times,~\bool_if:NTF #3 { lazy } { greedy } }
            {  0 } { #1~times }
          }
          {
            between~#1~and~\int_eval:n {#1+#2}~times,~
            \bool_if:NTF #3 { lazy } { greedy }
          }
      }
  }
```

(__regex_msg_repeated:nnN 定义结束。)

9.9 Code for tracing

There is a more extensive implementation of tracing in the l3trial package l3trace. Function names are a bit different but could be merged.

__regex_trace_push:nnN
__regex_trace_pop:nnN
__regex_trace:nne

Here #1 is the module name (regex) and #2 is typically 1. If the module's current tracing level is less than #2 show nothing, otherwise write #3 to the terminal.

```
\cs_new_protected:Npn \__regex_trace_push:nnN #1#2#3
  { \__regex_trace:nne {#1} {#2} { entering~ \token_to_str:N #3 } }
\cs_new_protected:Npn \__regex_trace_pop:nnN #1#2#3
  { \__regex_trace:nne {#1} {#2} { leaving~ \token_to_str:N #3 } }
\cs_new_protected:Npn \__regex_trace:nne #1#2#3
  {
    \int_compare:nNnF
      { \int_use:c { g__regex_trace_#1_int } } < {#2}
      { \iow_term:e { Trace:~#3 } }
  }
```

(*__regex_trace_push:nnN*, *__regex_trace_pop:nnN*, 和 *__regex_trace:nne* 定义结束。)

\g__regex_trace_regex_int

No tracing when that is zero.

```
\int_new:N \g__regex_trace_regex_int
```

(*\g__regex_trace_regex_int* 定义结束。)

__regex_trace_states:n

This function lists the contents of all states of the NFA, stored in \toks from 0 to \l__regex_max_state_int (excluded).

```
\cs_new_protected:Npn \__regex_trace_states:n #1
  {
    \int_step_inline:nnn
      \l__regex_min_state_int
      { \l__regex_max_state_int - 1 }
      {
        \__regex_trace:nne { regex } {#1}
          { \iow_char:N \\toks ##1 = { \__regex_toks_use:w ##1 } }
      }
  }
```

(*__regex_trace_states:n* 定义结束。)

```
⟨/package⟩
```

索引

斜体数字指向相应条目描述的页面，下划线数字指向定义的代码行，其它的都指向使用条目的页面。