Extending Python

Factorization in Primes
- flowchart and Python code
- timing: Python versus C

Writing a C program
- one main program
- using a function

Extending Python
- add Python.h and wrappers
- compiling and installing

Exercises and Summary

MCS 275 Lecture 2
Programming Tools and File Management
Jan Verschelde, 16 January 2008

Factorization in Primes

example of lecture 1

Input/Output specification:

input	:	a natural number n
output	:	a string $n = p_1\, p_2\, \cdots\, p_k$, $k > 0$
		where $n = p_1 \times p_2 \times \cdots \times p_k$
		and every p_i is prime, $i = 1, 2 \ldots, k$.

Running at the command prompt $:

```
$ python facnums.py
give a natural number n : 121121
121121 = 7 11 11 11 13
$
```

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Writing to Strings

delayed printing

If n is a number, then

```
print '%d = ', n
```

is equivalent to

```
s = '%d = ' % n
print s
```

The `'%d'` is a format string and the `%` following the string is the conversion operator.

We can update the string s as `s = s + '%d' % n` and postpone the printing of s till the end of the program.

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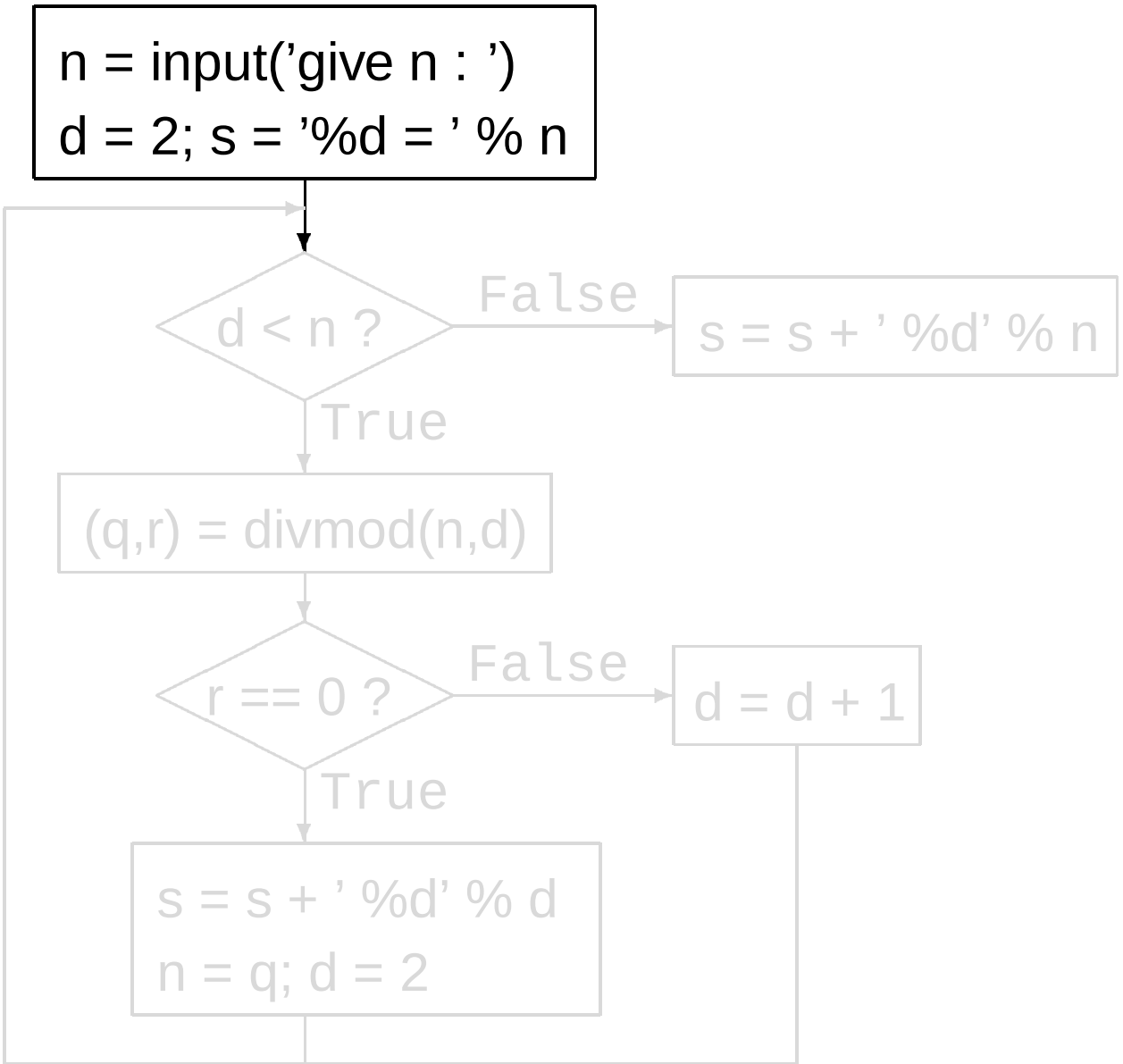
Extending Python

Flowchart for Factoring in Primes



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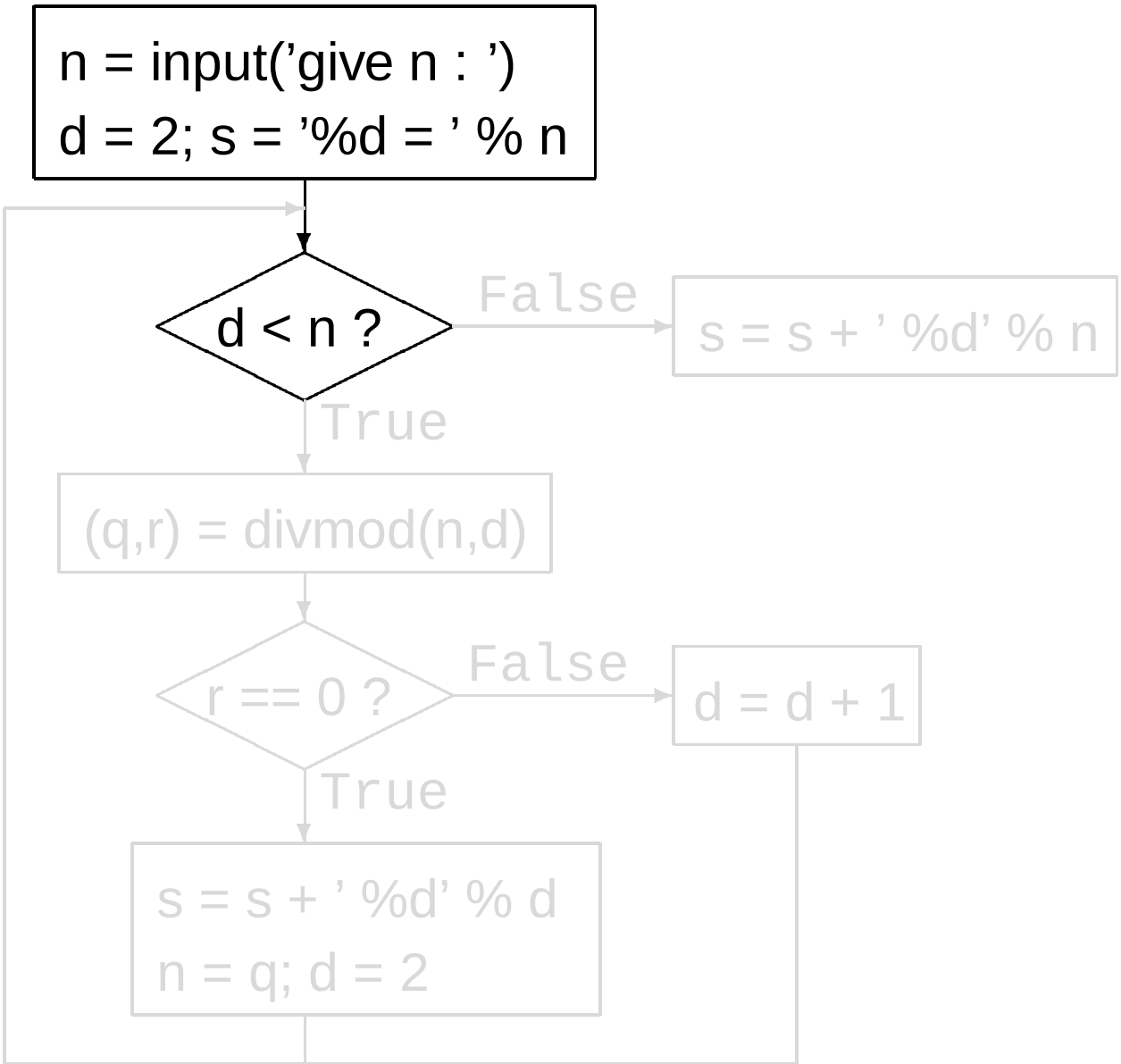

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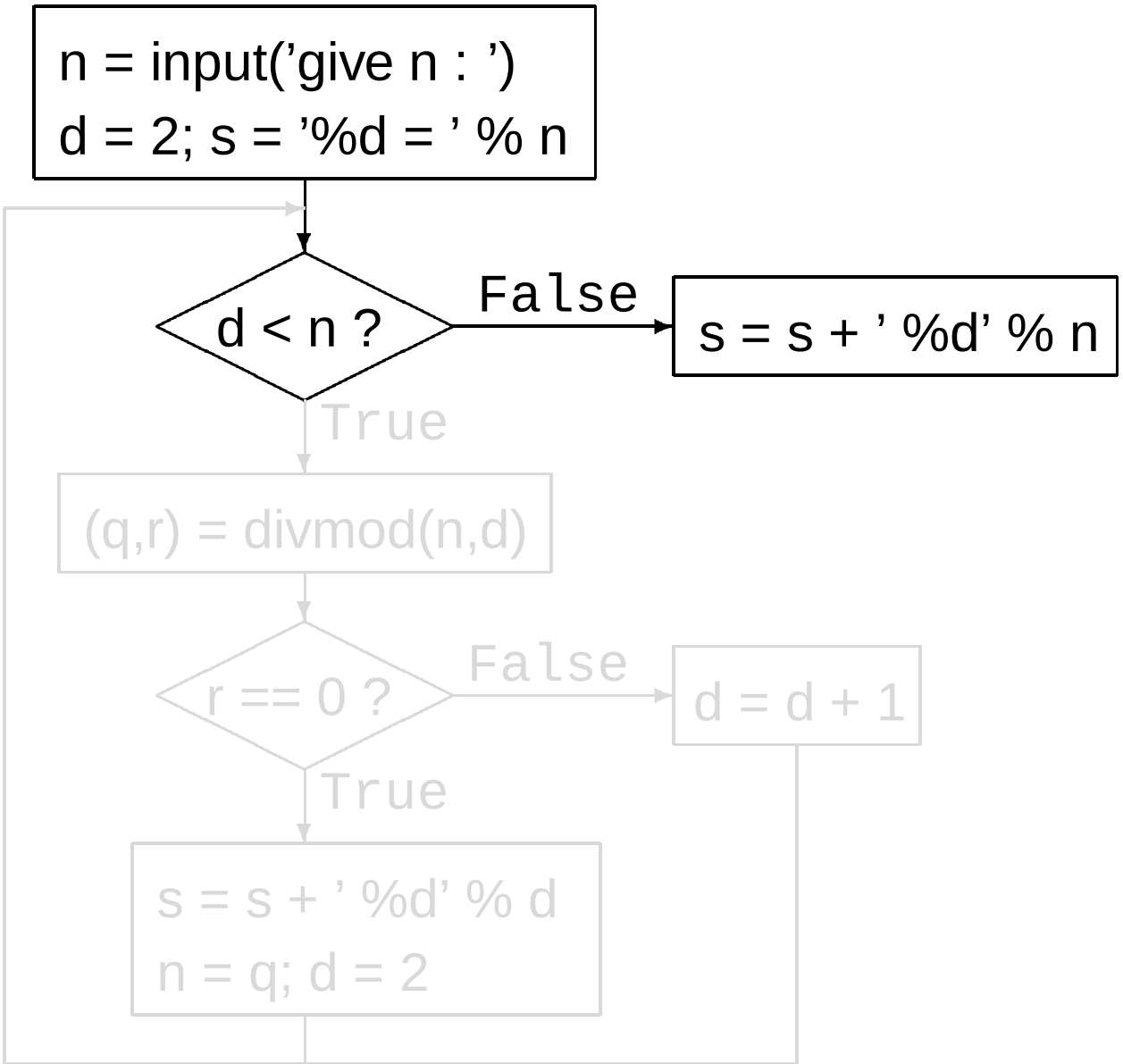

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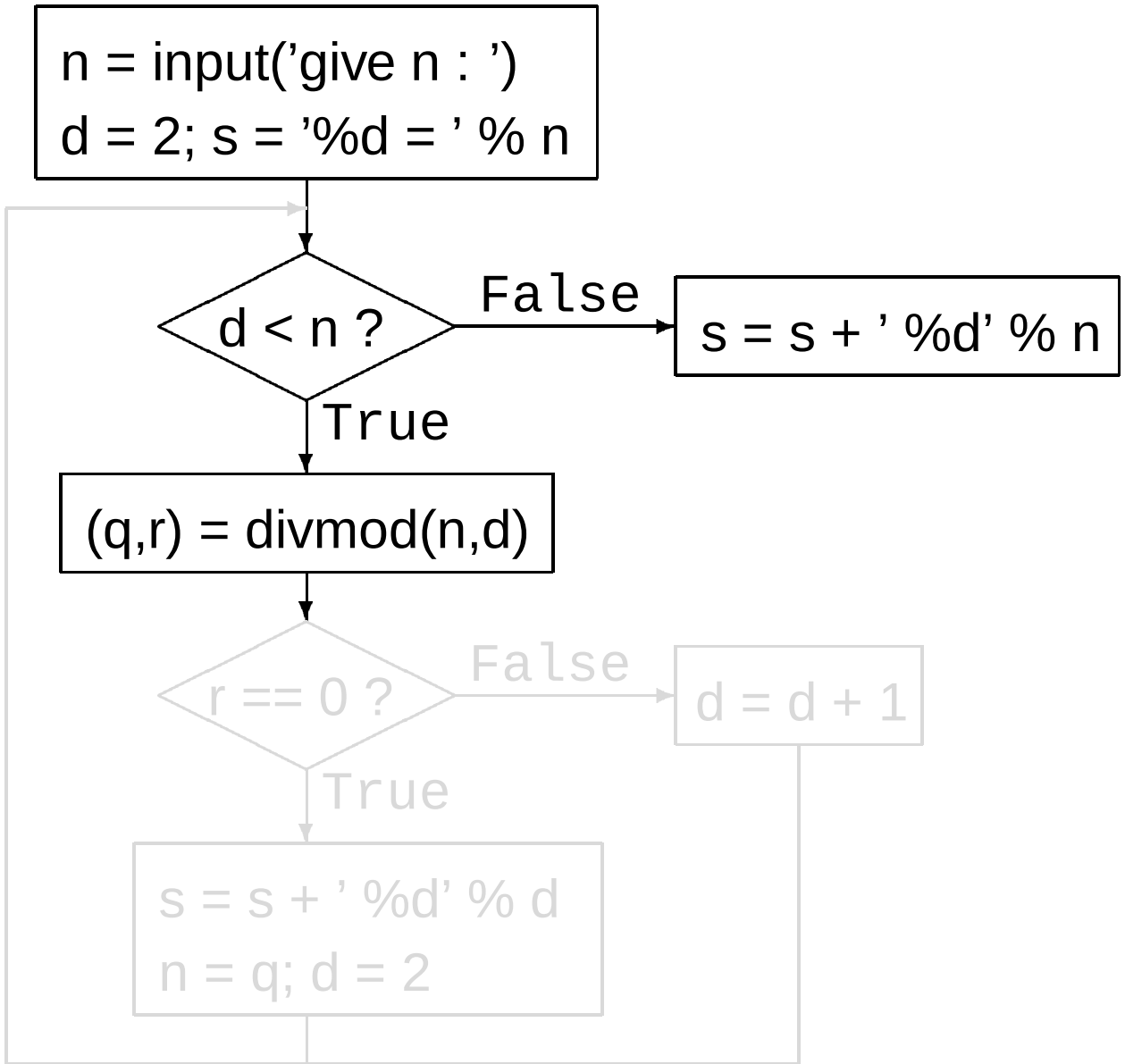

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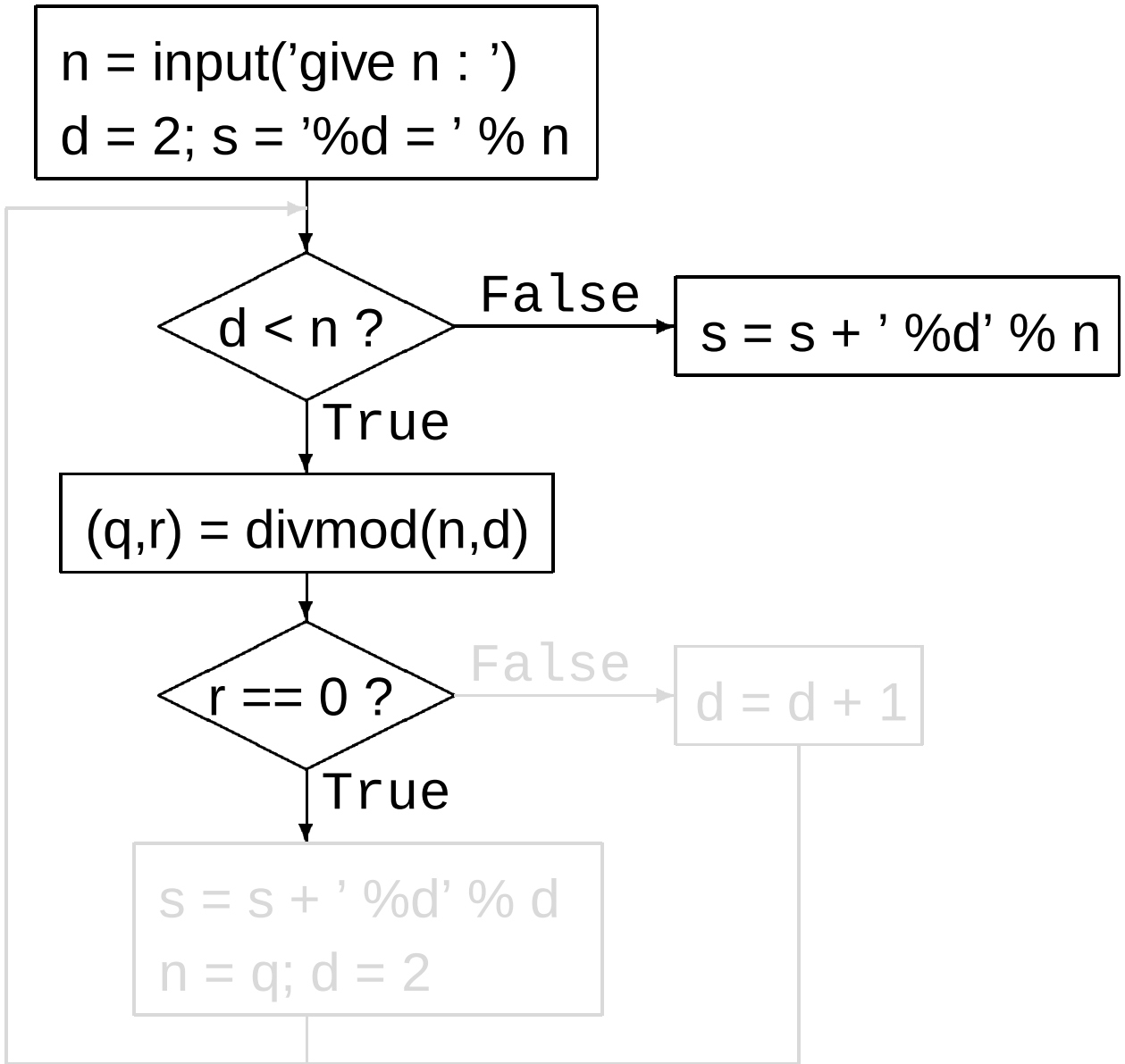

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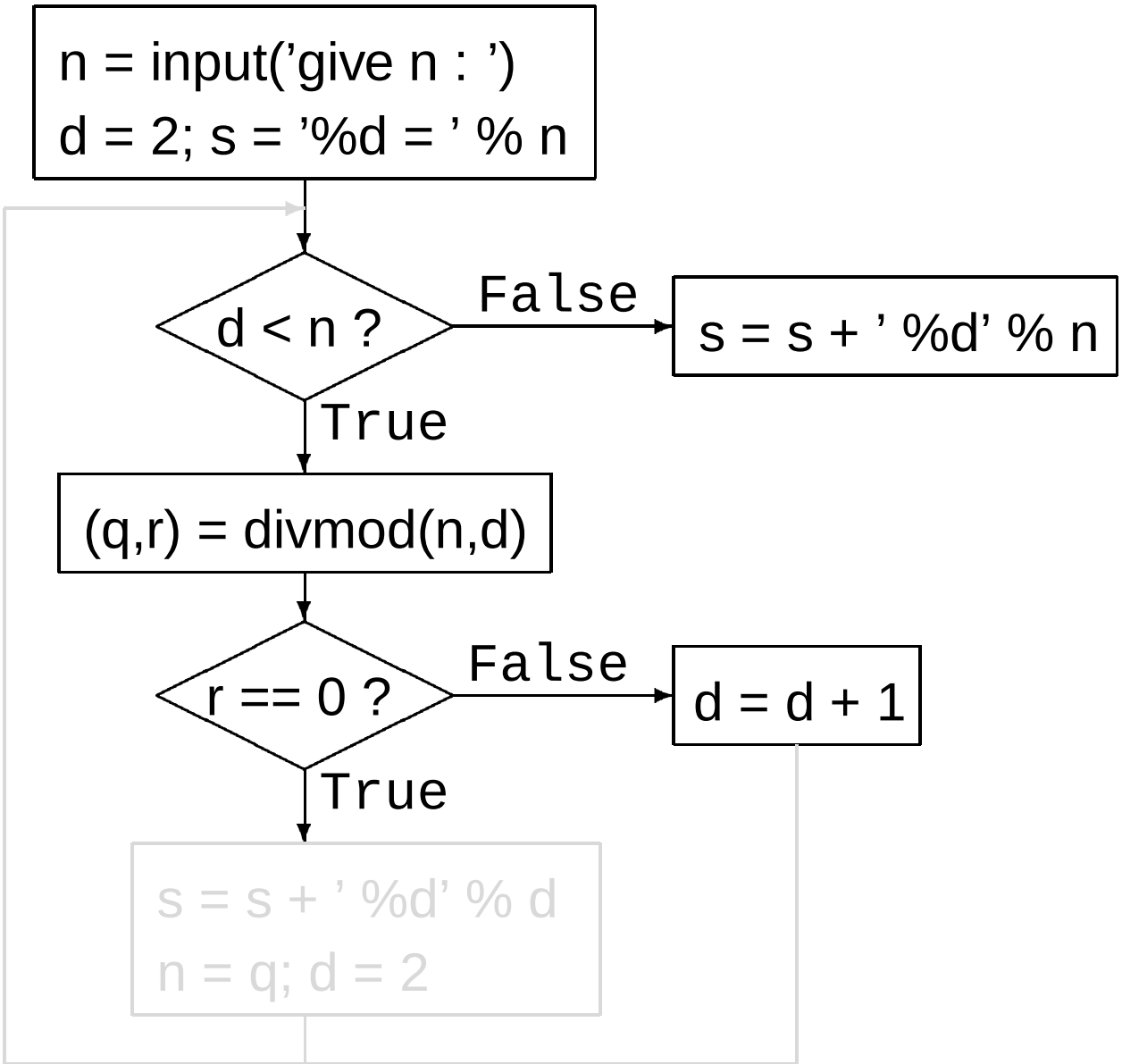

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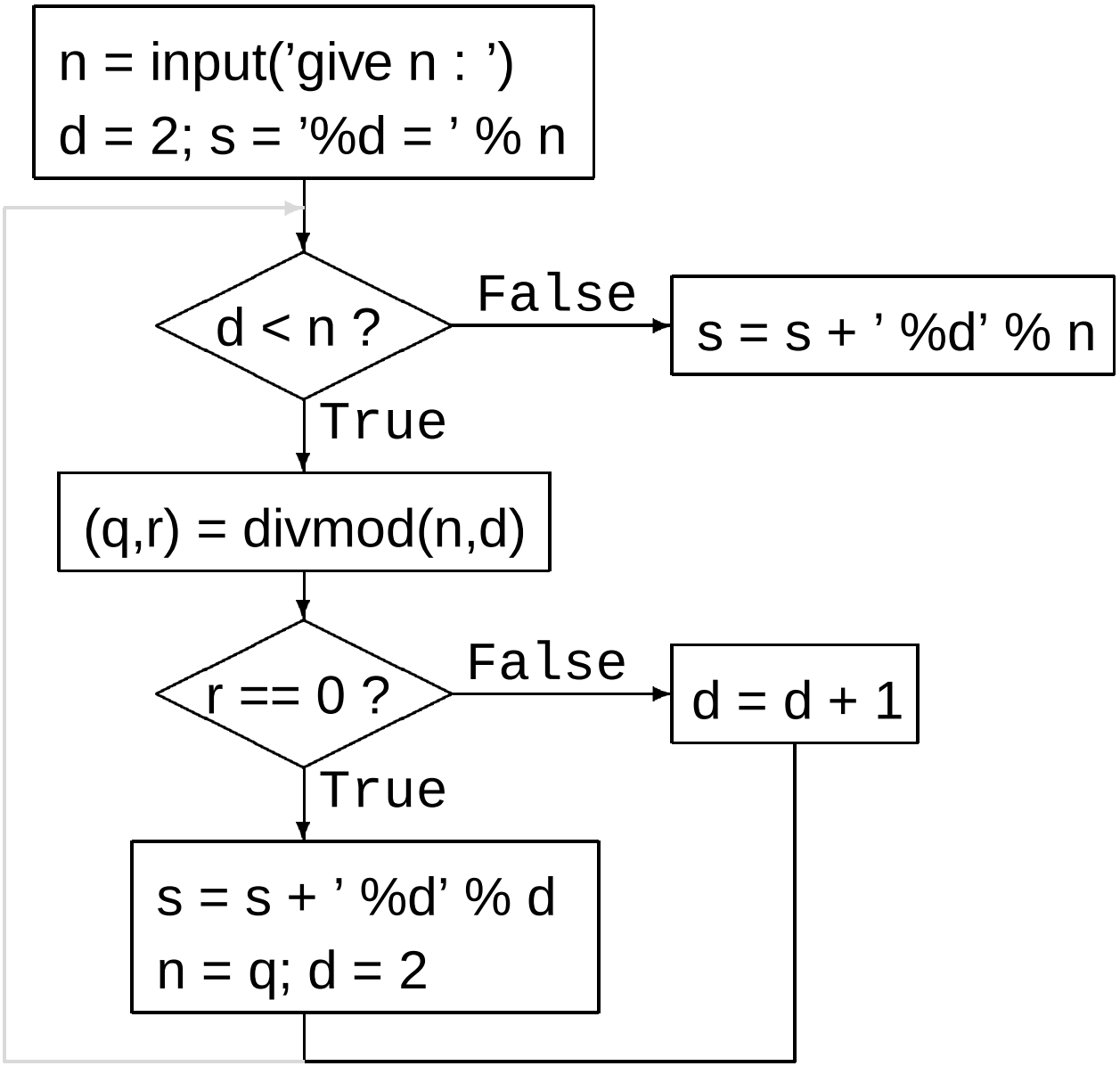

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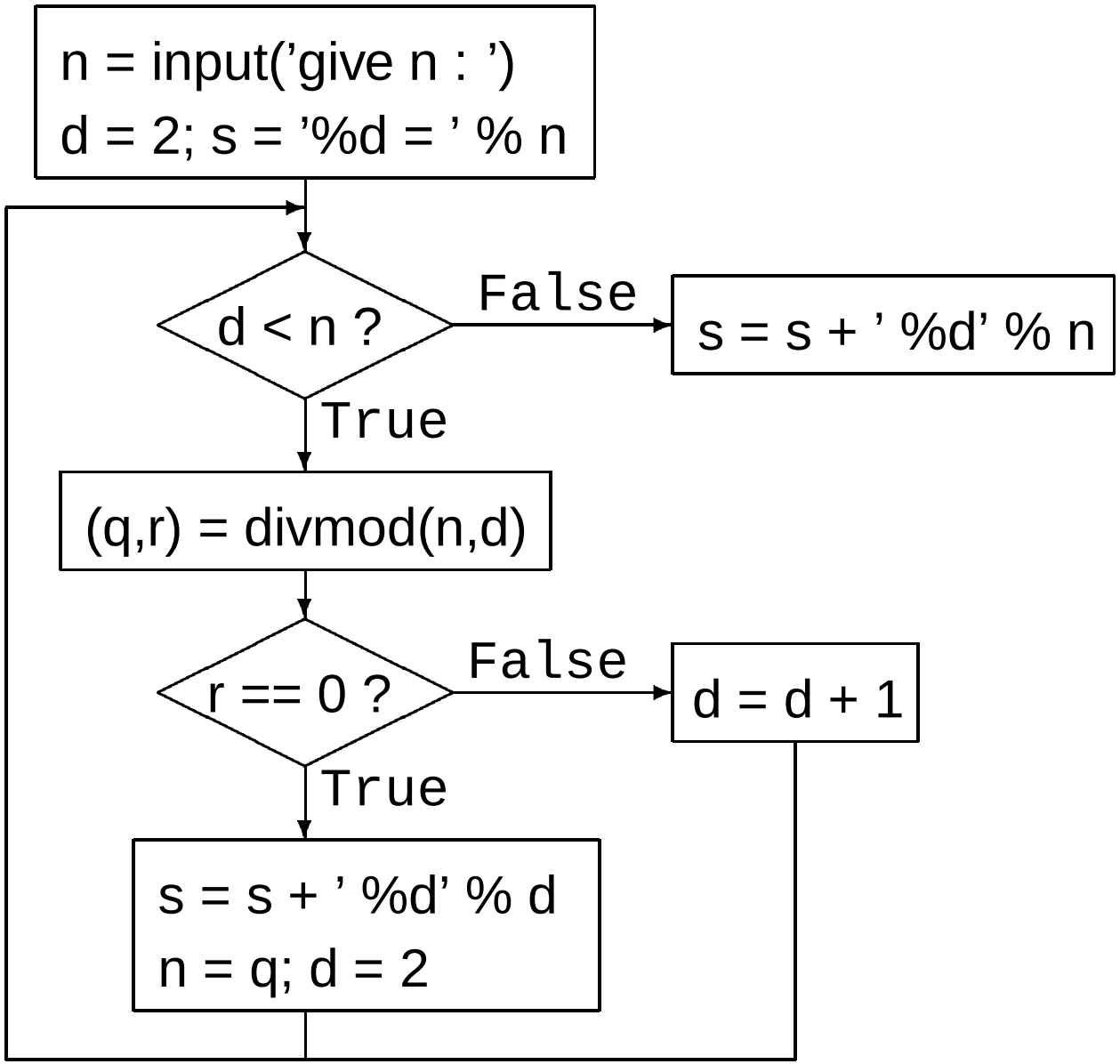

the script facnums.py

```
# MCS 275 L-2 Wed 14 Jan 2008 : facnums.py
# factor a number into product of primes,
# writing the result into a string

n = input('give a natural number n : ')
d = 2; s = '%d =' % n
while(d < n):
    (q,r) = divmod(n,d)
    if(r == 0):
        s = s + ' %d' % d
        n = q; d = 2
    else:
        d = d + 1
s = s + ' %d' % n
print s
```

Extending Python

Timing Programs

measuring performance empirically

- easiest: use `time` command
- slow typers take long time, so redirect input
- if the file `input` contains `121121`:

```
$ time python facnums.py < input
give a natural number n : 121121 = 7 11 11 11 13

real    0m0.022s
user    0m0.011s
sys     0m0.011s
```

It takes 22 milliseconds total,
half of which is spent on the user program,
the other half is time the system spent.

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Python versus C on 1000000007

```
$ time python facnums.py < input_prime
give a natural number n : 1000000007 = 1000000007

real    15m2.126s
user    15m1.454s
sys      0m0.585s
```

In 15 minutes, we wrote the C program `facnum0.c`,
we now compile it with `gcc`:

```
$ gcc -o /tmp/facnum0 facnum0.c
```

and run it on the same input:

```
$ time /tmp/facnum0 < input_prime
give a natural number n : 1000000007 = 1000000007

real    0m5.828s
user    0m5.816s
sys     0m0.012s
```

C is 150 times faster than Python!

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Extending Python

Variables and I/O in C

```
/* MCS 275 L-2 Wed 16 Jan 2008 : facnum0.c */

#include <stdio.h>

int main ( void )
{
   int n,d,r;

   printf("give a natural number n : ");
   scanf("%d",&n);

   printf("%d =",n);
```

- static typing: n, d, r are of type int
- stdio.h contains printf and scanf
- &n is the address of the variable n
- code is in between { and }

Variables and I/O in C

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Control Structures

program continued, with Python translation

```
    d = 2;                          | d = 2
    while(d < n)                    | while(d < n):
    {                               |
       r = n % d;                   |    r = n % d
       if(r == 0)                   |    if(r == 0):
       {                            |
          printf(" %d",d);          |       print ' %d' % d
          n = n/d;                  |       n = n/d
          d = 2;                    |       d = 2
       }                            |
       else                         |    else:
          d = d + 1;                |       d = d + 1
    }                               |
    printf(" %d\n",n);              | print ' %d\n' % n

    return 0;
}
```

Printing to Strings in C

The prime factors computed by the C program will be passed to Python in a string.

Therefore, the C code will print to a string.

```
printf("%d = ",n)
```

is equivalent to

```
char s[80]; /* 80 characters for result */
sprintf(s,"%d =",n); /* print to s */
```

Adding a factor d to the result s:

```
char f[10]; /* 10 characters for factor */
sprintf(f," %d",d);
strcat(s,f); /* string concatenation */
```

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Extending Python

using a function factor

```
#include <stdio.h>
#include <string.h>

int factor ( int n, char *s );
/* writes the prime factors of n
 * into the string s */

int main ( void )
{
   int n;
   char s[80]; /* string for result */

   printf("give a natural number n : ");
   scanf("%d",&n);
   factor(n,s);
   printf(s); /* print result */

   return 0;
}
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   return 0;
}
```

function definition

```
int factor ( int n, char *s ){
   int d,r;
   char f[10]; /* string for factor */
   sprintf(s,"%d =",n);
   d = 2;
   while(d < n){
      r = n % d;
      if(r == 0){
         sprintf(f," %d",d);
         strcat(s,f);
         n = n/d; d = 2;
      }
      else
         d = d + 1;
   }
   sprintf(f," %d\n",n);
   strcat(s,f);
   return 0;
}
```

Extending Python

The goal is to use the C code from a Python session.

The C code will in a *module* `NumFac`.

```
>>> import NumFac
>>> dir(NumFac)
['__doc__', '__file__', '__name__', 'factor',
'test']
>>> from NumFac import test, factor
>>> test()
give a natural number n : 121121
121121 = 7 11 11 11 13
>>> s = factor(121121,'')
>>> s
'121121 = 7 11 11 11 13\n'
>>> s.split(' ')
['121121', '=', '7', '11', '11', '11', '13\n']
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After the `split`, the factors are in a list.

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Extending Python

Python.h and test()

append to the file with the C code:

```
#include "/Library/Frameworks/Python.framework
/Headers/Python.h"
```

It is good practice to keep the main program as an interactive test program:

```
static PyObject *NumFac_test
  ( PyObject *self, PyObject *args )
{
   test();
   return (PyObject*)Py_BuildValue("");
}
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```

Wrapping the Function factor

```
static PyObject *NumFac_factor
   ( PyObject *self, PyObject *args )
{
   PyObject *result;
   int n;
   char s[80];

   if(!PyArg_ParseTuple(args,"is",&n,&s)) return NULL;

   factor(n,s);

   result = (PyObject*)Py_BuildValue("s",s);

   return result;
}
```

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Registration Table and Initialization

The registration table contains the documentation strings for the functions the module exports:

```
static PyMethodDef NumFacMethods[] =
{
   { "factor" , NumFac_factor , METH_VARARGS,
     "factor a natural number into primes" } ,
   { "test" , NumFac_test , METH_VARARGS,
     "interactive test on prime factoring" } ,
   { NULL , NULL, 0, NULL } ,
};

void initNumFac()   /* initialization function */
{
   Py_InitModule("NumFac",NumFacMethods);
}
```

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Extending Python

Compiling and Installing

To check whether the extension module is still valid C code, we compile as `gcc -c numfac.c`.

To create a *shareable object* (file with extension `.so`), we create setup.py:

```
from distutils.core import setup, Extension

# for using numfac.c :

MOD = 'NumFac'
setup(name=MOD,ext_modules=[Extension(MOD,\
  sources=['numfac.c'])])
```

and do `python setup.py build`
Instead of `python setup.py install`,
do `cp build/lib*/NumFac.so .`
(copy the shareable object to the current directory).

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Instead of `python setup.py install`,
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Exercises

1. Take the script `enumdivs.py` from Lecture 1 and write a corresponding C program: `enumdivs.c`. Write the factors to screen instead of into a list.
2. Modify the `enumdivs.c` from the previous exercise so that the factors are written into a string.
3. Use the modified `enumdivs.c` from the previous exercise to build a Python extension EnumDivs.
4. Take a Python function to compute the greatest common divisor of two natural numbers a and b:

```
s = 'gcd(%d,%d) = ' % (a,b)
r = a % b
while r <> 0:
   a = b
   b = r
   r = a % b
print s + '%d' % b
```

   Create a corresponding C program and use it to build a Python extension.

Summary

In this lecture we covered

1. some elements of C programs, see the start of Chapter 4 in *The Art & Craft of Computing*;
2. an introduction to extending Python, for more: `http://docs.python.org/ext/ext.html`.

On Friday we will start `numpy` and `scipy`,
go to `www.scipy.org` to download the code.