Mathematics for Computer Science

MIT 6.042J/18.062J

Computing GCD's The Euclidean Algorithm

GCD Remainder Lemma

Lemma:

gcd(a,b) = gcd(b, rem(a,b)) for $b \neq 0$

Proof: $a = qb + r$

any divisor of 2 of these terms must divide all 3.

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Proof: $a = qb + r$

so a,b and b,r have the same divisors

GCD example

Example: a = 899, b=493

GCD(899, 493) =

GCD(493, 406) =

GCD(406, 87) =

GCD(87, 58) =

GCD(58, 29) =

GCD(29, 0) = 29

Euclidean Algorithm

as a State Machine:

States ::= $\mathbb{N} \times \mathbb{N}$

start ::= (a,b)

state transitions defined by

$$(x,y) \longrightarrow (y, \text{rem}(x,y))$$

for $y \neq 0$

GCD partial correctness

By Lemma, gcd(x,y) is constant.
so preserved invariant is
P((x,y)) ::= [gcd(a,b) = gcd(x,y)]

P(start) is trivially true:
[gcd(a,b) = gcd(a,b)]

GCD partial correctness

at termination (if any)

$$x = \gcd(a,b)$$

Proof: at termination, y = 0, so

$$x = \gcd(x,0) = \underbrace{\gcd(x,y) = \gcd(a,b)}_{\text{preserved invariant}}$$

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At each transition, x is replaced by y. If $y \leq x/2$, then x gets halved at this step. If $y > x/2$, then $\text{rem}(x,y) = x - y < x/2$, so y gets halved when it is replaced by $\text{rem}(x,y)$ after the next step.

GCD Termination

y halves or smaller at every other step, so reaches minimum in $\leq$

$$2 \log_2 b$$

steps.