

a) Minimum finding + subtraction:

- Each processor finds the minimum element in its block.
- Each processor sends the minimum element it found to processor zero
- synchronize
- Processor zero finds the smallest minimum (linear, loop over P elements).
- Processor zero sends the minimum to all processors.
- synchronize
- Each processor subtracts the minimum from the element in its block.

Runtime:

- Computation :  $2 \cdot \text{ceiling}(N/P) + P$
- Communication:  $2 \cdot P$
- Synchronization: 2

$$T_{\min} = 2 \cdot \text{ceiling}(N/P) + P + 2 \cdot P \cdot l + 2 \cdot g$$

b) Psuedocode:

N := length of input  
S := Current Processor Number  
X := input vector (global)  
Y := output vector (global)  
P := # of processors  
K := amount of shift (  $1 \leq K \leq N$  )

For( $i := S \cdot \text{ceiling}(N/P)$ ;  $i < \min( (S+1) \cdot \text{ceiling}(N/P), N$ );  $i++$ )  
     $Y[(i+k)\%n] = X[i]$

Runtime:

- Computation:  $\text{ceiling}(N/P)$
- Communication: 0
- Synchronization: 0

$$T_{\text{shift}} = \text{ceiling}(N/P)$$

c)