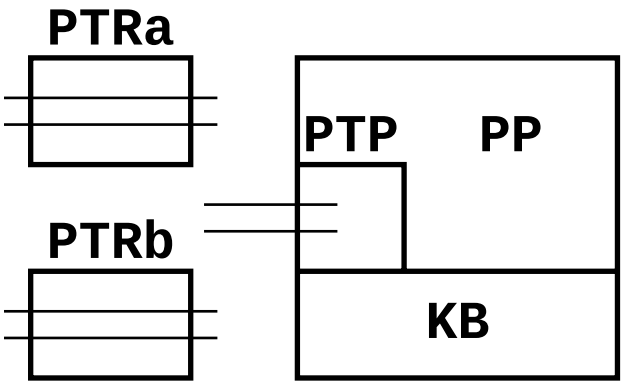
## The I/O System




## Expressions

$$\begin{matrix}\text{L}\\\text{S}\end{matrix}\left\{\begin{matrix}\text{<int>}\times\text{<int>}\\\text{<int>}\end{matrix}\right\}\pm\left\{\begin{matrix}\text{<int>}\times\text{<int>}\\\text{<int>}\end{matrix}\right\}\pm\ \ldots\ \pm\left\{\begin{matrix}\text{<int>}\times\text{<int>}\\\text{<int>}\end{matrix}\right\}=$$

## Instructions

| | | |
|---|---|---|
| Copy mode | $\begin{matrix}\text{L}\\\text{S}\end{matrix}$ | Output $\begin{matrix}\text{L}\\\text{S}\end{matrix}$ and move to Comp mode. |
| | Others | Output the character. |
| Comp mode | `a` | Switch to PTR `a`. |
| | `b` | Switch to PTR `b`. |
| | `c` | If acc is positive, switch to PTR `b`. |
| | `k` | Switch to keyboard. |
| | `g` | Output the next character. |
| | `.` | Move to Copy mode. Written as $\Gamma$ with subscripts. |
| | `,` | Output acc, move to Copy mode. |
| | `=` | Output acc, reset acc to 0, move to Copy mode. |
| | `+ - x` digits | Data to computer. |
| | $\begin{matrix}\text{L}\\\text{S}\end{matrix}$ | Ignore. |
| | Others | Stop the PTR. |

**Autocorrelation**

$f(t_0) \times f(t_0) + f(t_1) \times f(t_1) + \cdots + f(t_{n-1}) \times f(t_{n-1})$
$f(t_0) \times f(t_1) + f(t_1) \times f(t_2) + \cdots + f(t_{n-1}) \times f(t_0)$
$f(t_0) \times f(t_2) + f(t_1) \times f(t_3) + \cdots + f(t_{n-1}) \times f(t_1)$

PTR b

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$\underset{\mathrm{S}}{\mathrm{L}}\ f(t_0)\ \times\ \mathtt{a}\ f(t_1)\ \times\ \mathtt{a}\ f(t_2)\ \times\ \mathtt{a}\ \cdots\ f(t_{n-1})\ \times\ \mathtt{a}\ \mathtt{0}\ \times\ \mathtt{a}\ \mathtt{0} = \hookleftarrow$

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PTR a

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$f(t_0)\ +\ \mathtt{b}\ f(t_1)\ +\ \mathtt{b}\ f(t_2)\ +\ \mathtt{b}\ \cdots\ f(t_{n-1})\ +\ \mathtt{b} \hookleftarrow$

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**Table of $\alpha x_i^2 + \beta x_i + \gamma$ for $x_i = a_0 + ih$**

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$, \mathtt{ab}\ \underset{\mathrm{S}}{\mathrm{L}}\ + h \hookleftarrow$

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E.g. to prepare a tape for $x = 0, 1, 2, \ldots$, after typing 0,

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$, \mathtt{ab}\ \underset{\mathrm{S}}{\mathrm{L}}\ + \mathtt{1} \hookleftarrow$

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The output tape:

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$\mathtt{0}\ \mathtt{ab}\ \underset{\mathrm{S}}{\mathrm{L}}\ \mathtt{1}\ \mathtt{ab}\ \underset{\mathrm{S}}{\mathrm{L}}\ \mathtt{2}\ \mathtt{ab}\ \underset{\mathrm{S}}{\mathrm{L}}\ \mathtt{3}\ \mathtt{ab} \cdots$

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When we wish to stop at $x = 10$, use PTR a,

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$, \mathtt{ab}\ \underset{\mathrm{S}}{\mathrm{L}}\ - \mathtt{10} + \mathtt{c}\ \mathtt{11} \hookleftarrow$

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Function tape:

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$\underset{\mathrm{S}}{\mathrm{L}}\ \alpha\ \times\ \mathtt{ab}\ +\ \beta\ =\ \times\ \mathtt{ab}\ +\ \gamma\ = \hookleftarrow$

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From these two tapes,

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$\underset{\mathrm{S}}{\mathrm{L}}\ \overline{\alpha x_i + \beta}\ \times\ \mathtt{ab} +\ \gamma\ = \underset{\mathrm{S}}{\mathrm{L}}\ \overline{\alpha x_{i+1} + \beta}\ \times\ \mathtt{ab} +\ \gamma = \cdots$

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**Tape for** $\begin{pmatrix} A & B \\ C & D \end{pmatrix} \times \begin{pmatrix} E & F \\ G & H \end{pmatrix}$

PTR b

$$A\ \mathtt{a}\ B\ \mathtt{a}\ C\ \mathtt{a}\ D\ \mathtt{a}\ E\ \mathtt{a}\ F\ \mathtt{a}\ G\ \mathtt{a}\ H\ \mathtt{a}$$

PTR a

$$\overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{b} = \Gamma_1\ \Gamma_2 \cdots \Gamma_8\ \ \overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{b} = \Gamma_2\ \Gamma_3 \cdots \Gamma_8 \qquad A\ B$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{g}\Gamma_2\ \mathtt{b} = \Gamma_3\ \Gamma_4 \cdots \Gamma_8\ \ \overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{g}\Gamma_2\ \mathtt{g}\Gamma_3\ \mathtt{b} = \Gamma_4\ \Gamma_5 \cdots \Gamma_8 \qquad C\ D$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{g}\Gamma_2 \cdots \mathtt{g}\Gamma_4\ \mathtt{b} = \Gamma_5\ \Gamma_6 \cdots \Gamma_8\ \ \overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{g}\Gamma_2 \cdots \mathtt{g}\Gamma_5\ \mathtt{b} = \Gamma_6\ \Gamma_7\ \Gamma_8 \qquad E\ F$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{g}\Gamma_2 \cdots \mathtt{g}\Gamma_6\ \mathtt{b} = \Gamma_7\ \Gamma_8\ \ \overset{\mathrm{L}}{\mathrm{S}}\ \mathtt{g}\Gamma_1\ \mathtt{g}\Gamma_2 \cdots \mathtt{g}\Gamma_7\ \mathtt{b} = \Gamma_8 \qquad G\ H$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \mathtt{g}\Gamma_2\ \mathtt{g}\Gamma_3 \cdots \mathtt{g}\Gamma_8\ \ ,\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_4\ \mathtt{g}\Gamma_6\ \mathtt{g}\Gamma_7\ \mathtt{g}\Gamma_8\ \ ,+$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1\ \mathtt{g}\Gamma_3\ \mathtt{g}\Gamma_4 \cdots \mathtt{g}\Gamma_8\ \ ,\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_6\ \mathtt{g}\Gamma_8\ \ ,=,\overset{\mathrm{S}}{\mathrm{P}}$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \mathtt{g}\Gamma_2\ \mathtt{g}\Gamma_3 \cdots \mathtt{g}\Gamma_8\ \ =\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_5\ \mathtt{g}\Gamma_7\ \mathtt{g}\Gamma_8\ \ ,+$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1\ \mathtt{g}\Gamma_3\ \mathtt{g}\Gamma_4 \cdots \mathtt{g}\Gamma_8\ \ =\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_7\ \ ,=\overset{\mathrm{C}}{\mathrm{R}}\ \overset{\mathrm{L}}{\mathrm{F}}$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1\ \Gamma_2\ \mathtt{g}\Gamma_4\ \mathtt{g}\Gamma_5 \cdots \mathtt{g}\Gamma_8\ \ ,\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_4\ \mathtt{g}\Gamma_6\ \mathtt{g}\Gamma_7\ \mathtt{g}\Gamma_8\ \ =+$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_3\ \mathtt{g}\Gamma_5\ \mathtt{g}\Gamma_6 \cdots \mathtt{g}\Gamma_8\ \ ,\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_6\ \mathtt{g}\Gamma_8\ \ ==,\overset{\mathrm{S}}{\mathrm{P}}$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1\ \Gamma_2\ \mathtt{g}\Gamma_4\ \mathtt{g}\Gamma_5 \cdots \mathtt{g}\Gamma_8\ \ =\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_5\ \mathtt{g}\Gamma_7\ \mathtt{g}\Gamma_8\ \ =+$$

$$\overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_3\ \mathtt{g}\Gamma_5\ \mathtt{g}\Gamma_6 \cdots \mathtt{g}\Gamma_8\ \ =\times\ \overset{\mathrm{L}}{\mathrm{S}}\ \Gamma_0\ \Gamma_1 \cdots \Gamma_7\ \ ==\overset{\mathrm{C}}{\mathrm{R}}\ \overset{\mathrm{L}}{\mathrm{F}}$$

The output after 1 process:

$$\frac{\mathrm{L}}{\mathrm{S}}\ A\ \Gamma_1\ \Gamma_2\ \cdots\ \Gamma_8\ \ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \ B\ \Gamma_2\ \Gamma_3\ \cdots\ \Gamma_8$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \ C\ \Gamma_3\ \Gamma_4\ \cdots\ \Gamma_8\ \ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \Gamma_3\ \ D\ \Gamma_4\ \Gamma_5\ \cdots\ \Gamma_8$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \cdots\ \Gamma_4\ \ E\ \Gamma_5\ \Gamma_6\ \cdots\ \Gamma_8\ \ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \cdots\ \Gamma_5\ \ F\ \Gamma_6\ \Gamma_7\ \Gamma_8$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \cdots\ \Gamma_6\ \ G\ \Gamma_7\ \Gamma_8\ \ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \cdots\ \Gamma_7\ \ H\ \Gamma_8$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \mathrm{g}\Gamma_2\ \mathrm{g}\Gamma_3\ \cdots\ \mathrm{g}\Gamma_8\ \ ,\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_4\ \mathrm{g}\Gamma_6\ \mathrm{g}\Gamma_7\ \mathrm{g}\Gamma_8\ \ ,+ \qquad A\ E$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \mathrm{g}\Gamma_3\ \mathrm{g}\Gamma_4\ \cdots\ \mathrm{g}\Gamma_8\ \ ,\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_6\ \mathrm{g}\Gamma_8\ \ ,=\ ,\frac{\mathrm{S}}{\mathrm{P}} \qquad B\ G$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \mathrm{g}\Gamma_2\ \mathrm{g}\Gamma_3\ \cdots\ \mathrm{g}\Gamma_8\ \ =\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_5\ \mathrm{g}\Gamma_7\ \mathrm{g}\Gamma_8\ \ ,+ \qquad A\ F$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \mathrm{g}\Gamma_3\ \mathrm{g}\Gamma_4\ \cdots\ \mathrm{g}\Gamma_8\ \ =\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_7\ \ ,=\ \frac{\mathrm{C}}{\mathrm{R}}\ \frac{\mathrm{L}}{\mathrm{F}} \qquad B\ H$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \mathrm{g}\Gamma_4\ \mathrm{g}\Gamma_5\ \cdots\ \mathrm{g}\Gamma_8\ \ ,\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_4\ \mathrm{g}\Gamma_6\ \mathrm{g}\Gamma_7\ \mathrm{g}\Gamma_8\ \ =+ \qquad C\ E$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_3\ \mathrm{g}\Gamma_5\ \mathrm{g}\Gamma_6\ \cdots\ \mathrm{g}\Gamma_8\ \ ,\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_6\ \mathrm{g}\Gamma_8\ \ =\ ,\frac{\mathrm{S}}{\mathrm{P}} \qquad D\ G$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \Gamma_2\ \mathrm{g}\Gamma_4\ \mathrm{g}\Gamma_5\ \cdots\ \mathrm{g}\Gamma_8\ \ =\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_5\ \mathrm{g}\Gamma_7\ \mathrm{g}\Gamma_8\ \ =+ \qquad C\ F$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_3\ \mathrm{g}\Gamma_5\ \mathrm{g}\Gamma_6\ \cdots\ \mathrm{g}\Gamma_8\ \ =\times\ \frac{\mathrm{L}}{\mathrm{S}}\ \Gamma_1\ \cdots\ \Gamma_7\ \ =\ =\ \frac{\mathrm{C}}{\mathrm{R}}\ \frac{\mathrm{L}}{\mathrm{F}} \qquad D\ H$$

The output after 8 processes:

$$\frac{\mathrm{L}}{\mathrm{S}}\ A\times E+B\times G=\ ,\frac{\mathrm{S}}{\mathrm{P}}\ \frac{\mathrm{L}}{\mathrm{S}}\ A\times F+B\times H=\ \frac{\mathrm{C}}{\mathrm{R}}\ \frac{\mathrm{L}}{\mathrm{F}}$$

$$\frac{\mathrm{L}}{\mathrm{S}}\ C\times E+D\times G=\ ,\frac{\mathrm{S}}{\mathrm{P}}\ \frac{\mathrm{L}}{\mathrm{S}}\ C\times F+D\times H=\ \frac{\mathrm{C}}{\mathrm{R}}\ \frac{\mathrm{L}}{\mathrm{F}}$$