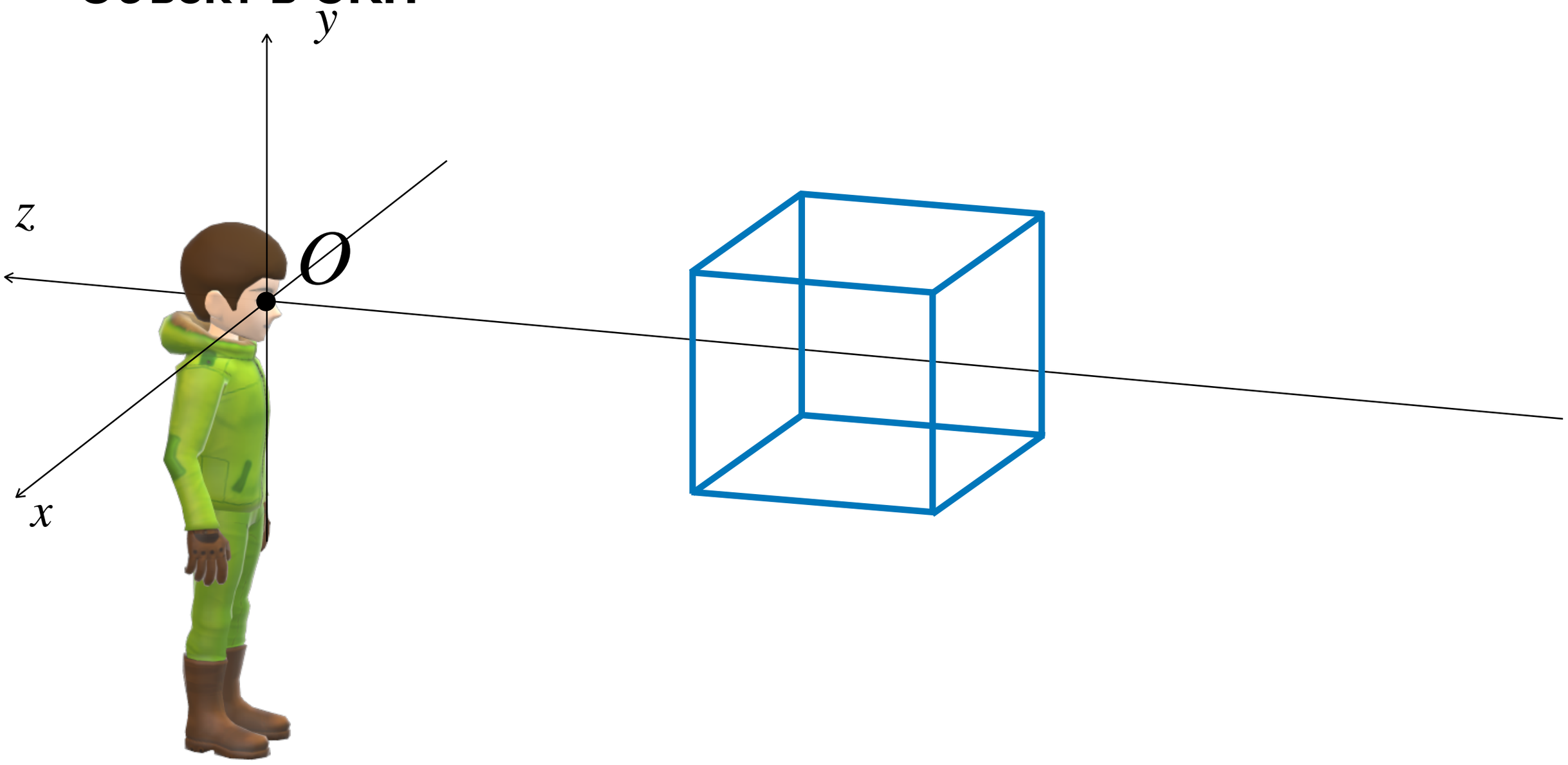
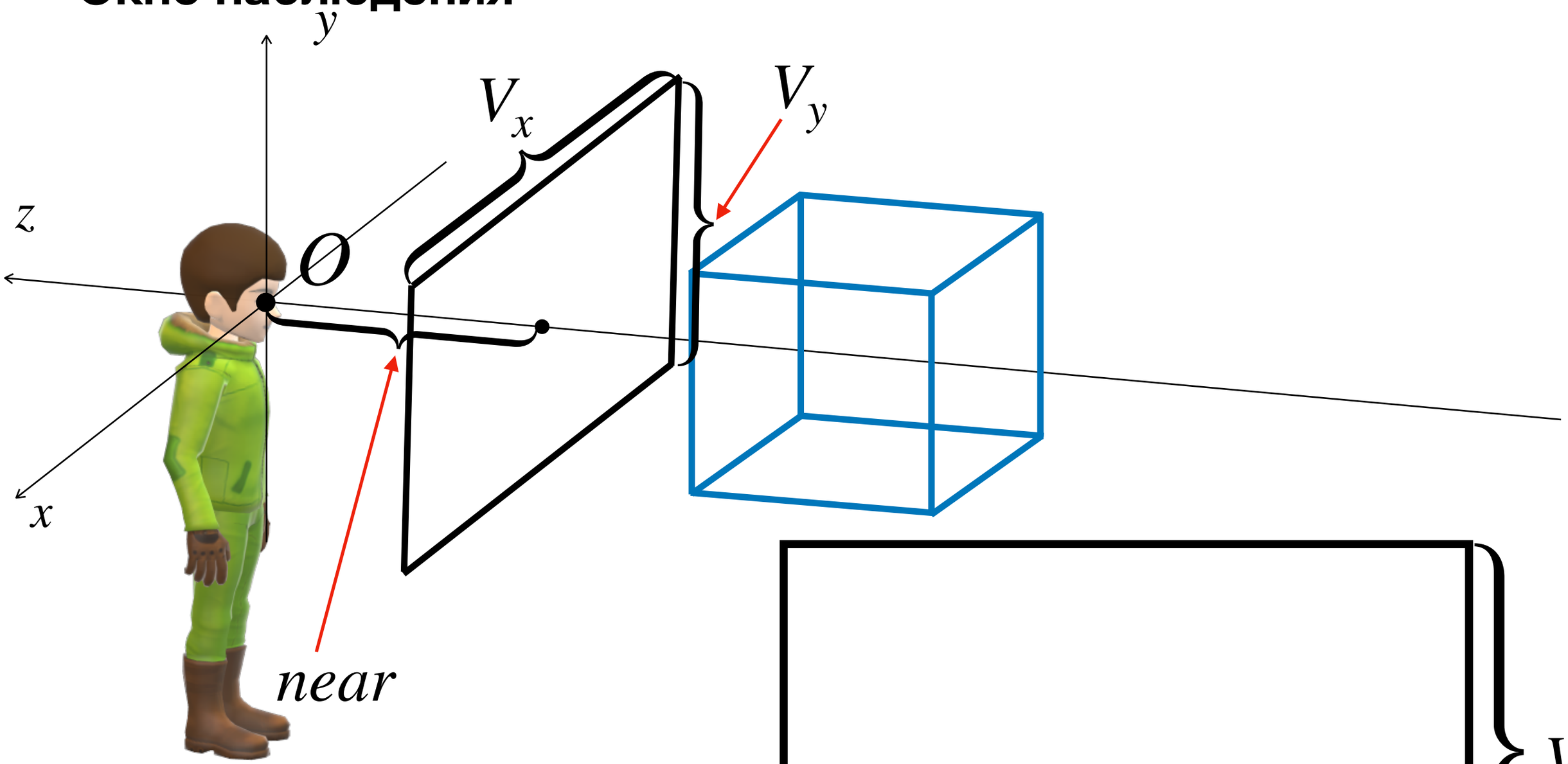
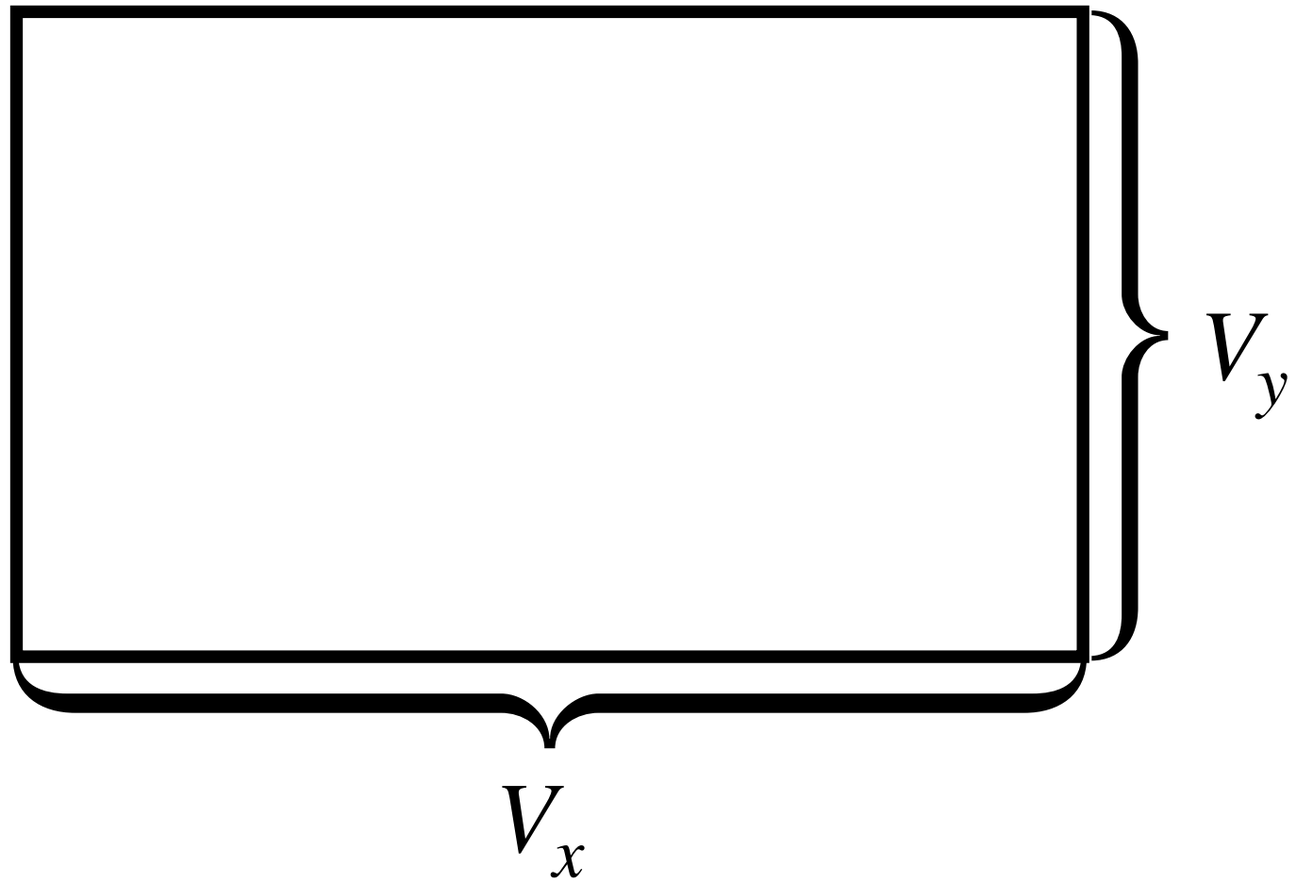
Трехмерные проекции

Объект в СКН



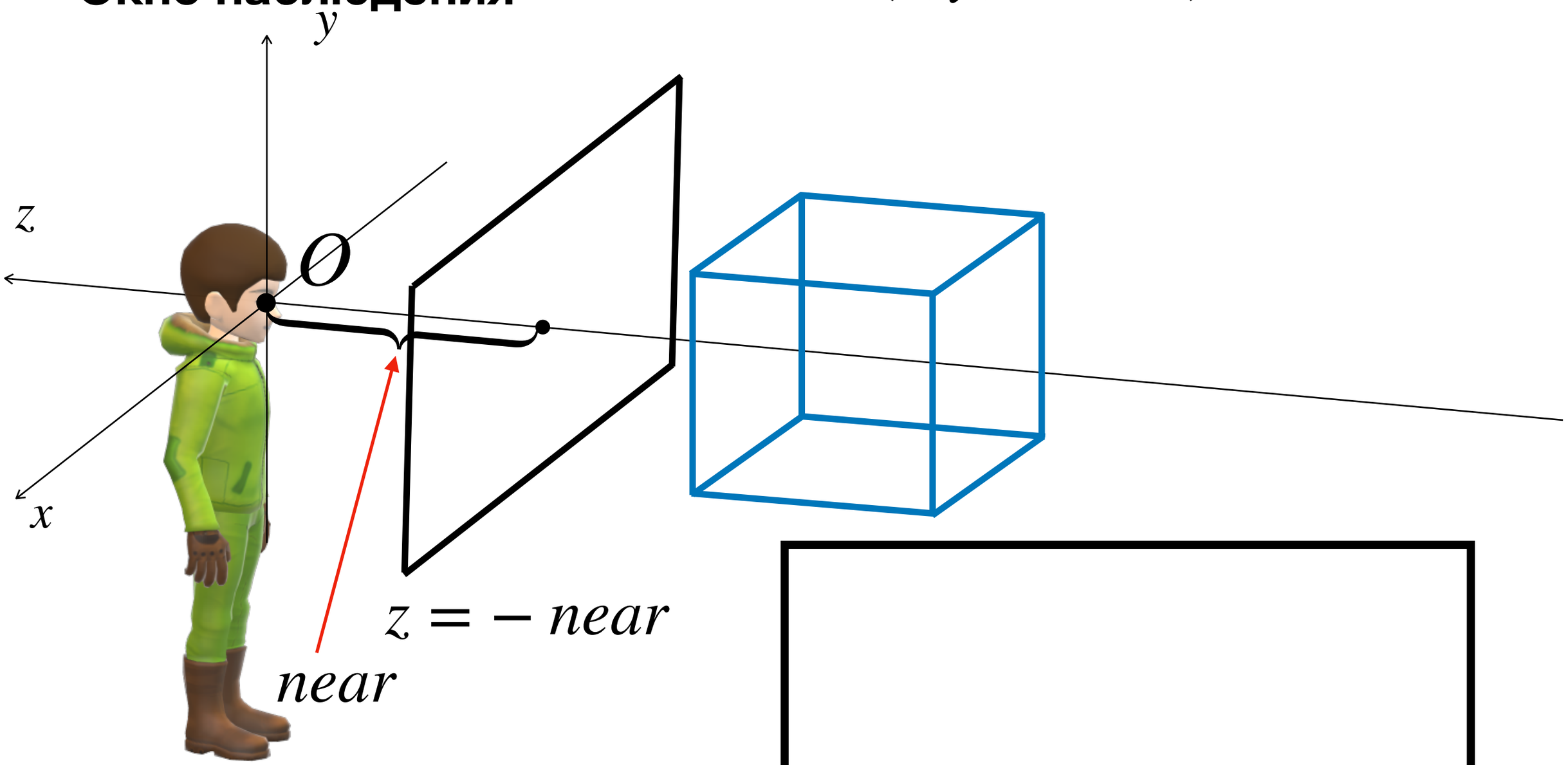
Окно наблюдения



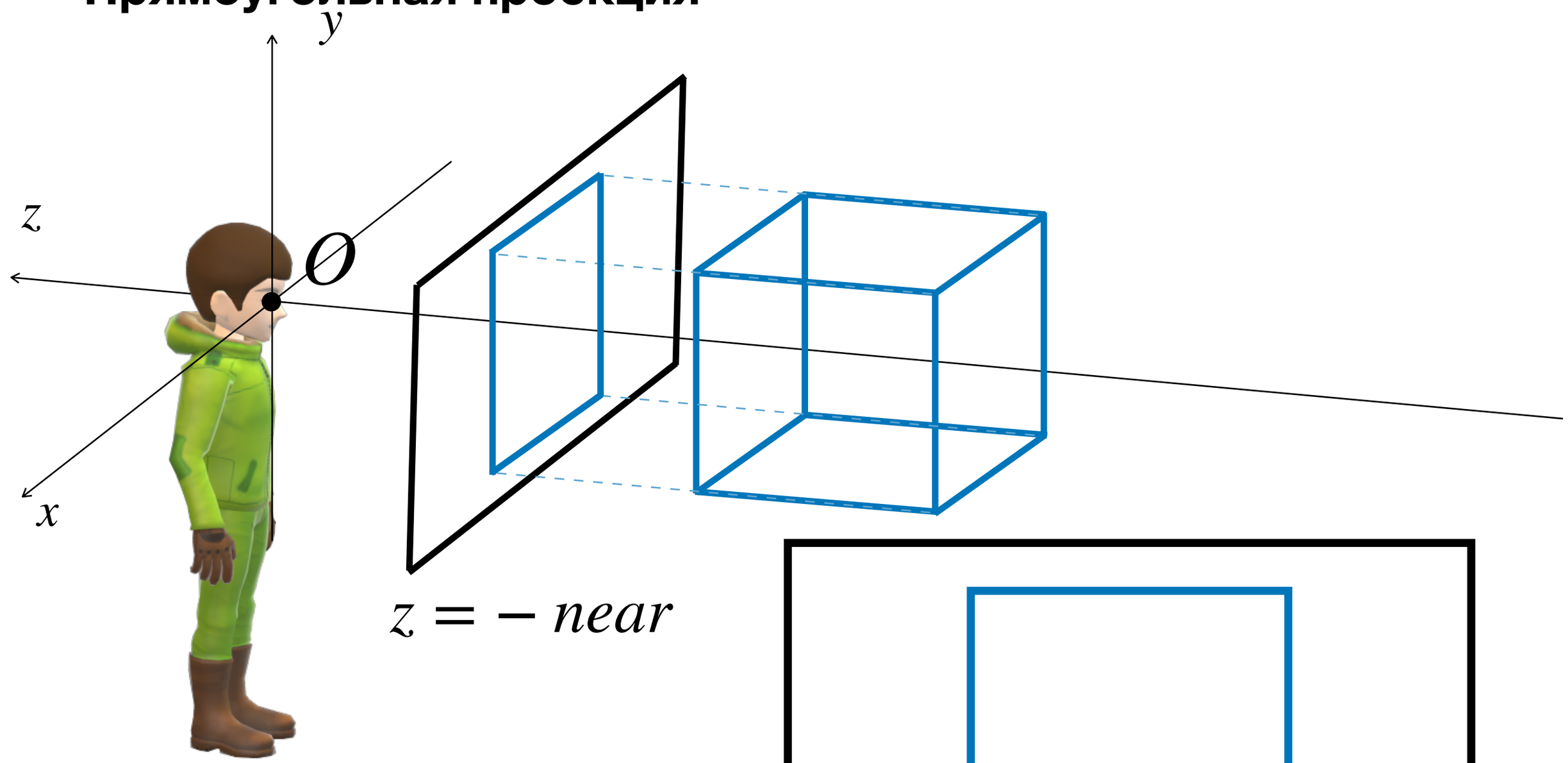


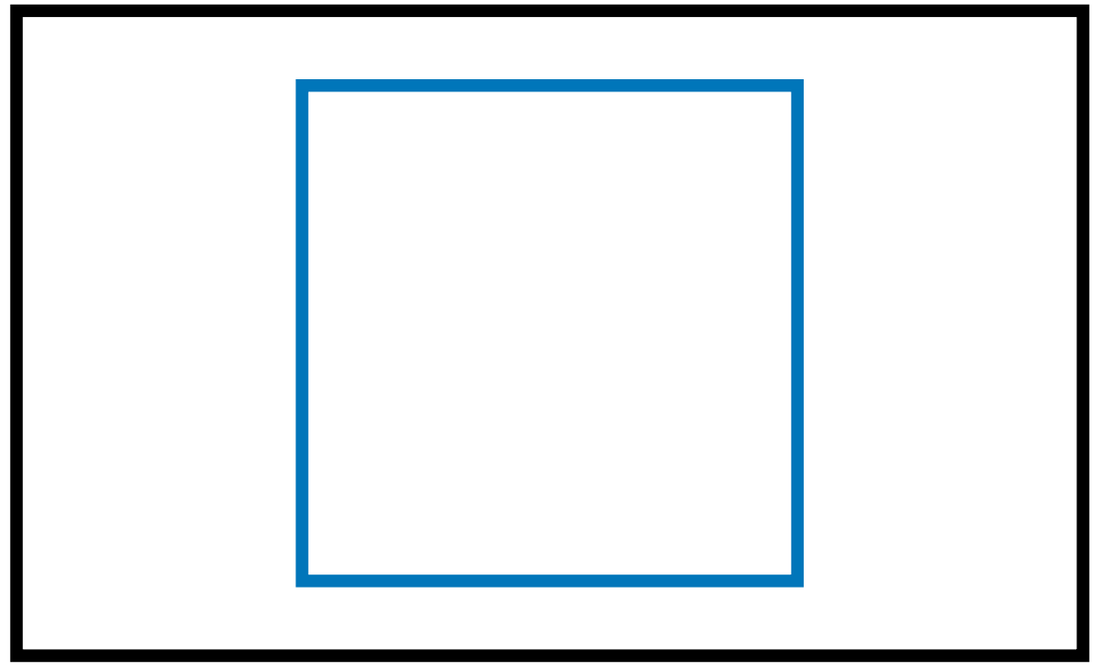
Окно наблюдения

$(x, y, -near)$

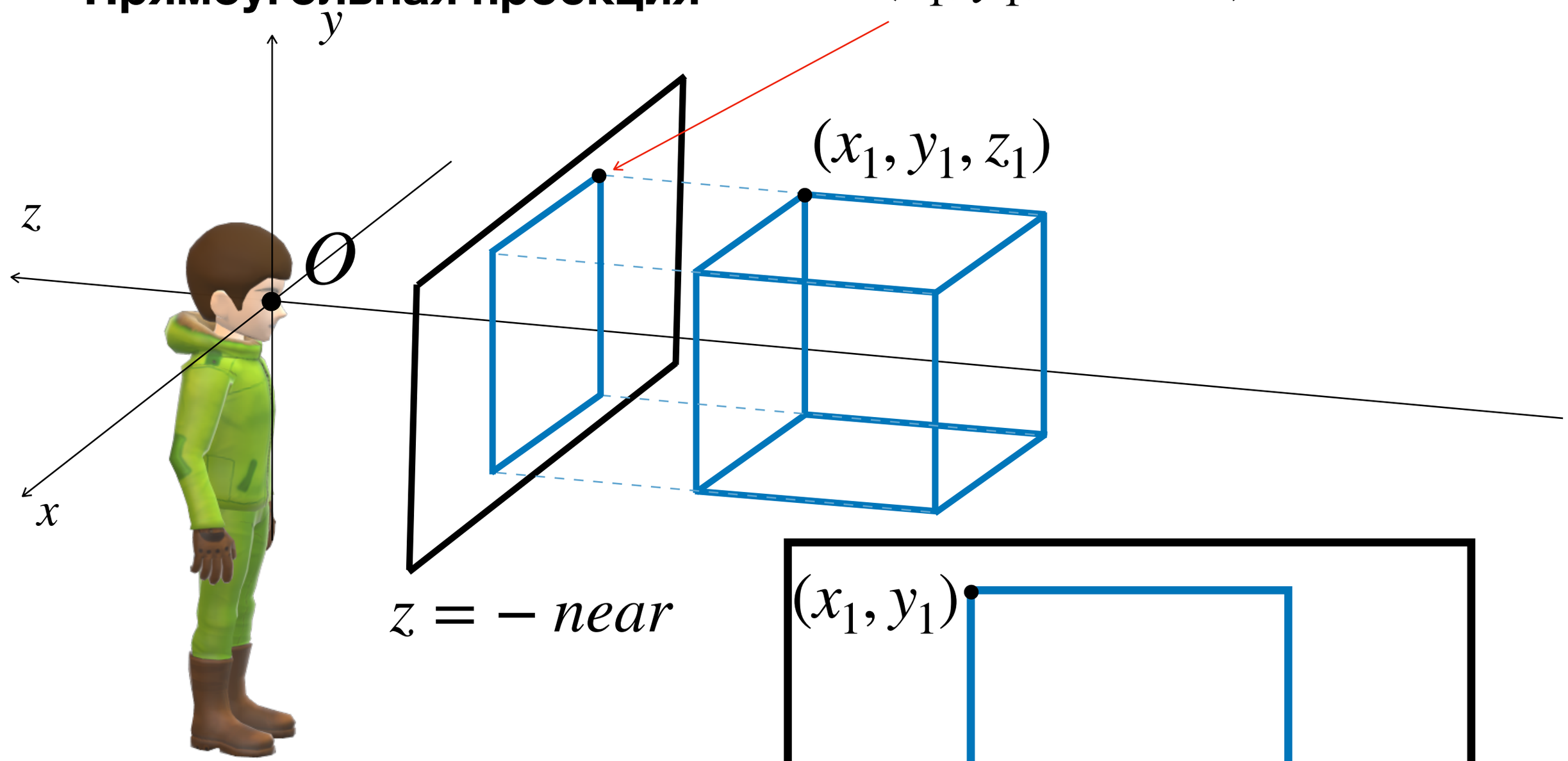


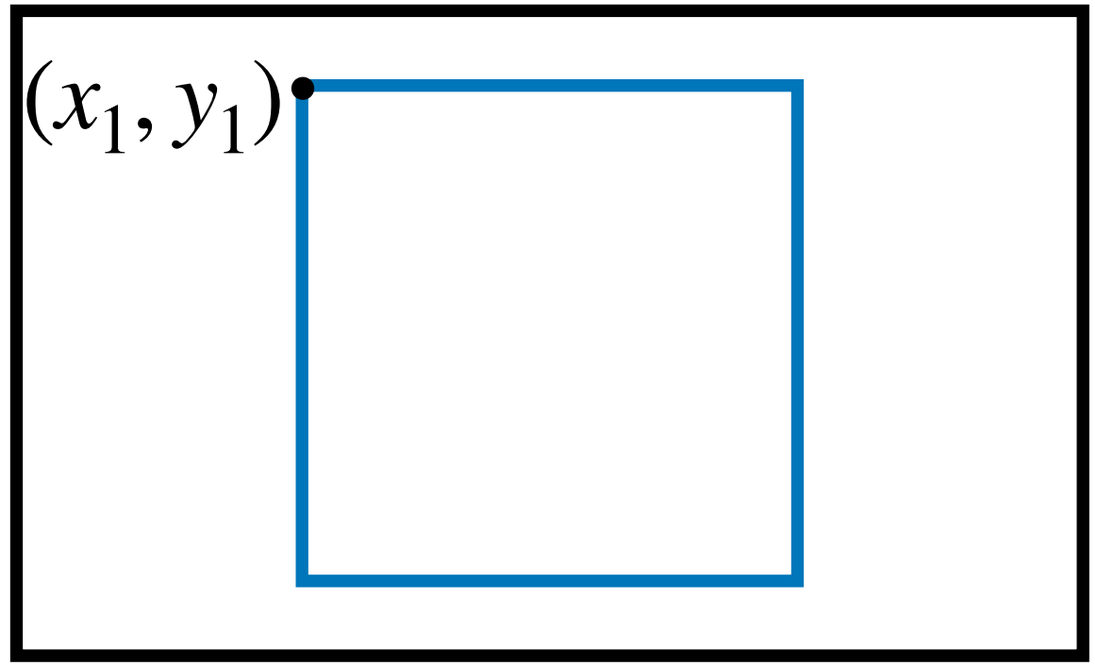
Прямоугольная проекция



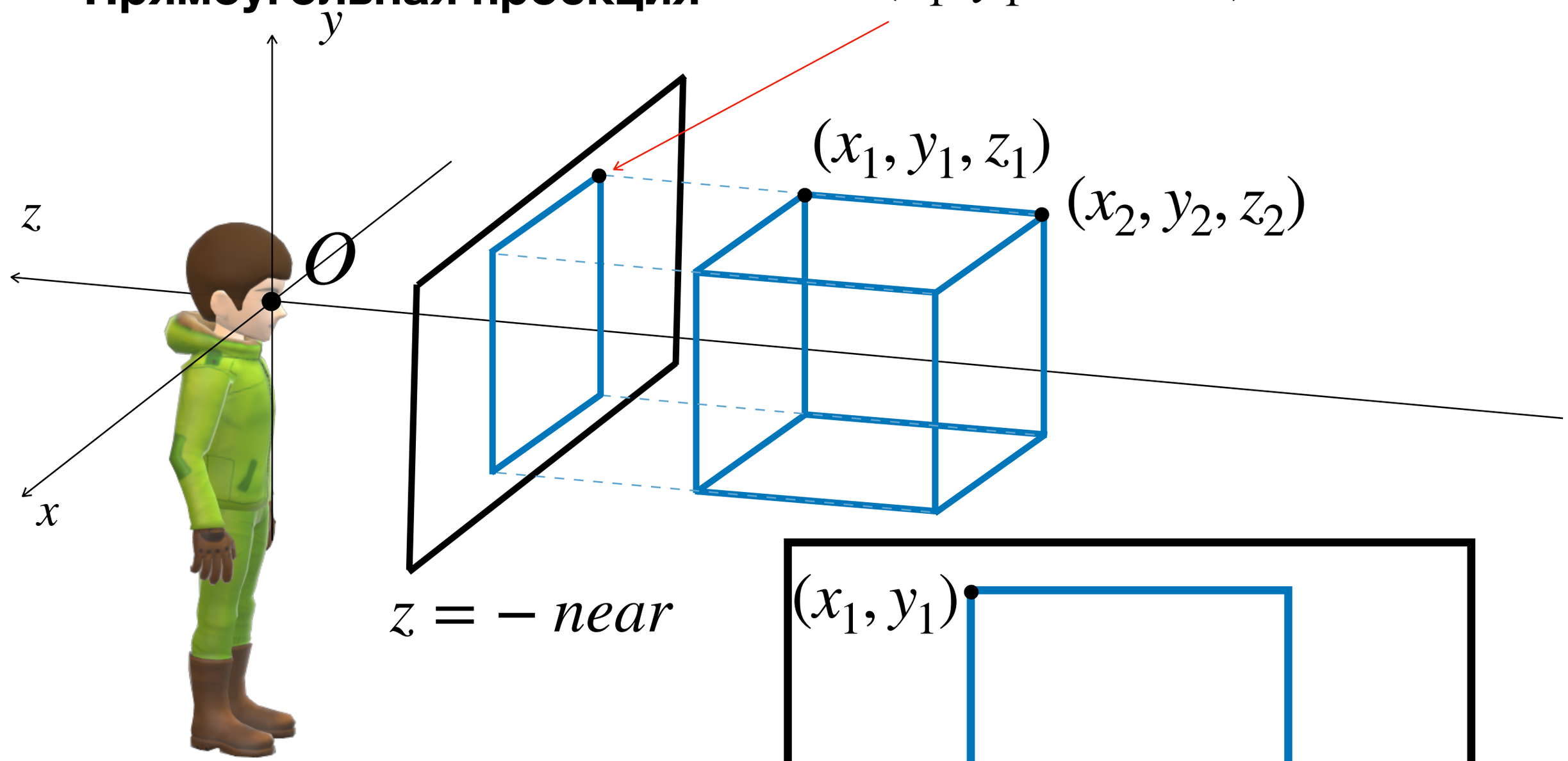


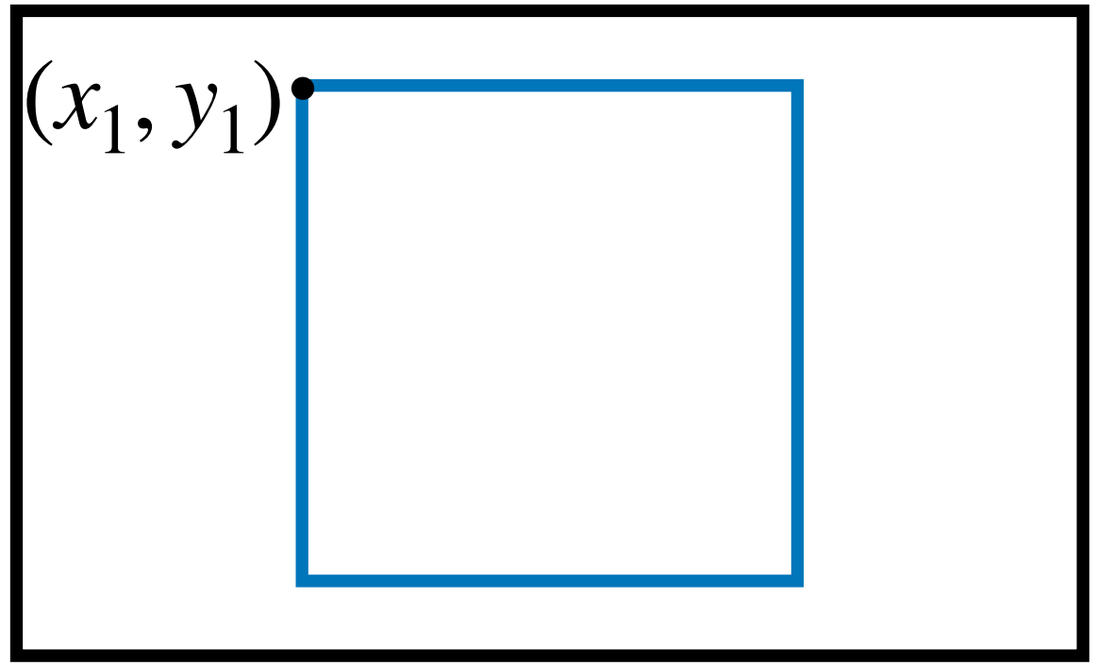
Прямоугольная проекция



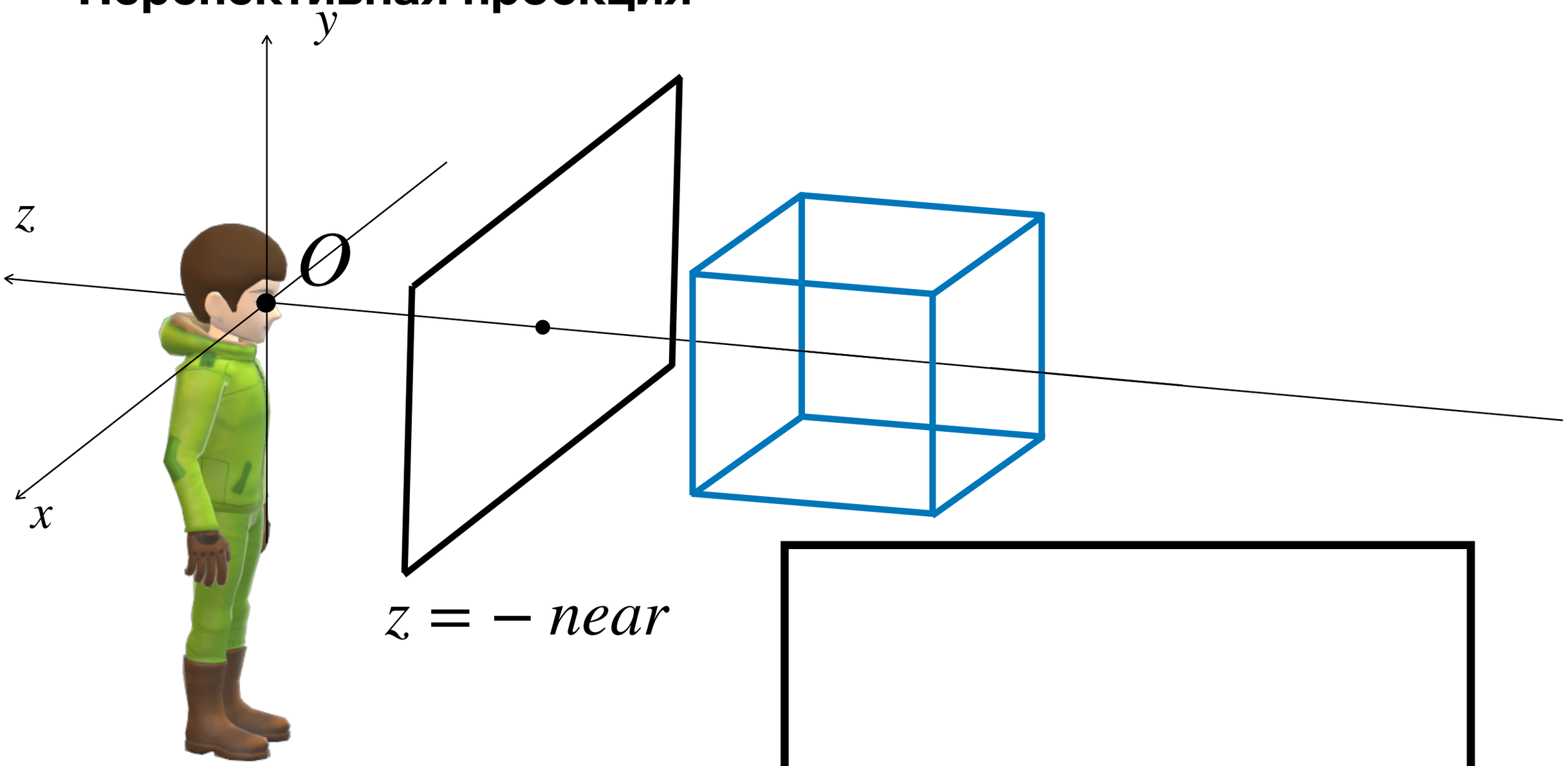


Прямоугольная проекция





Перспективная проекция



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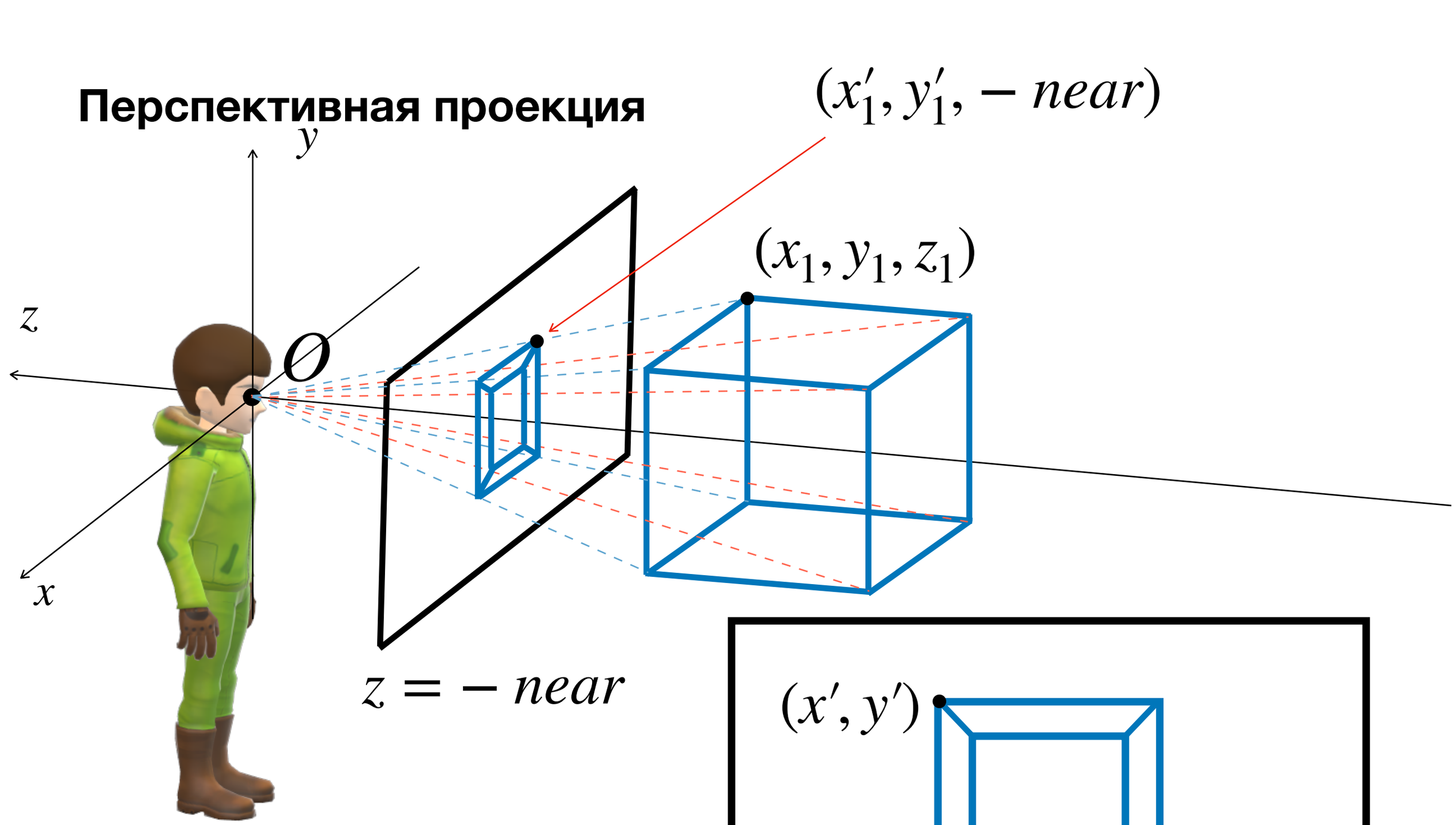

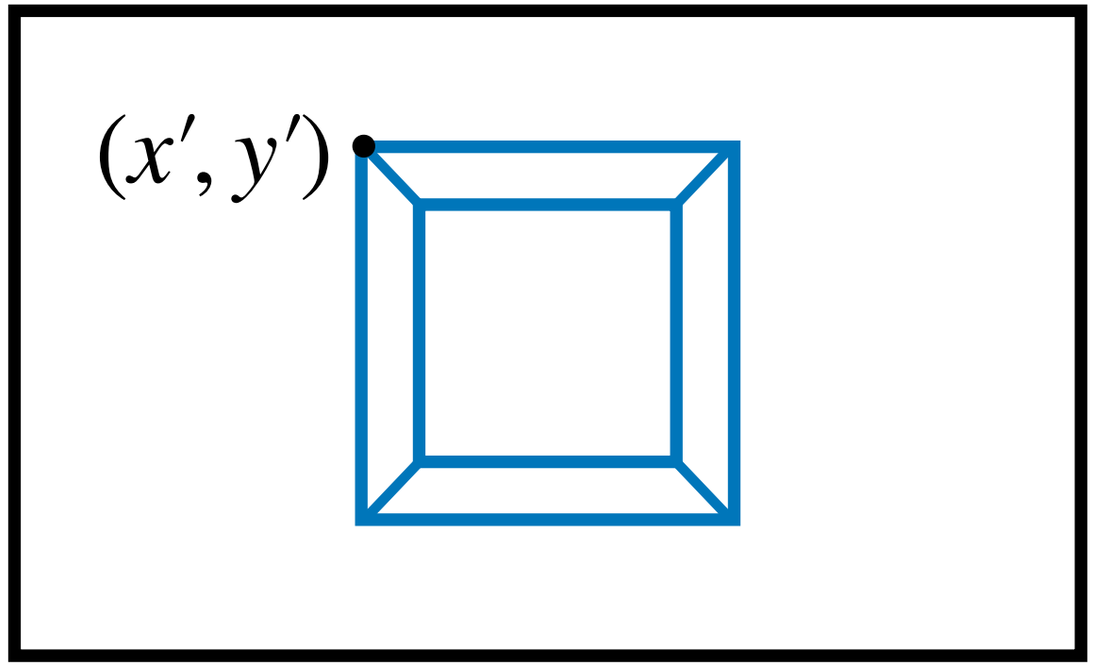

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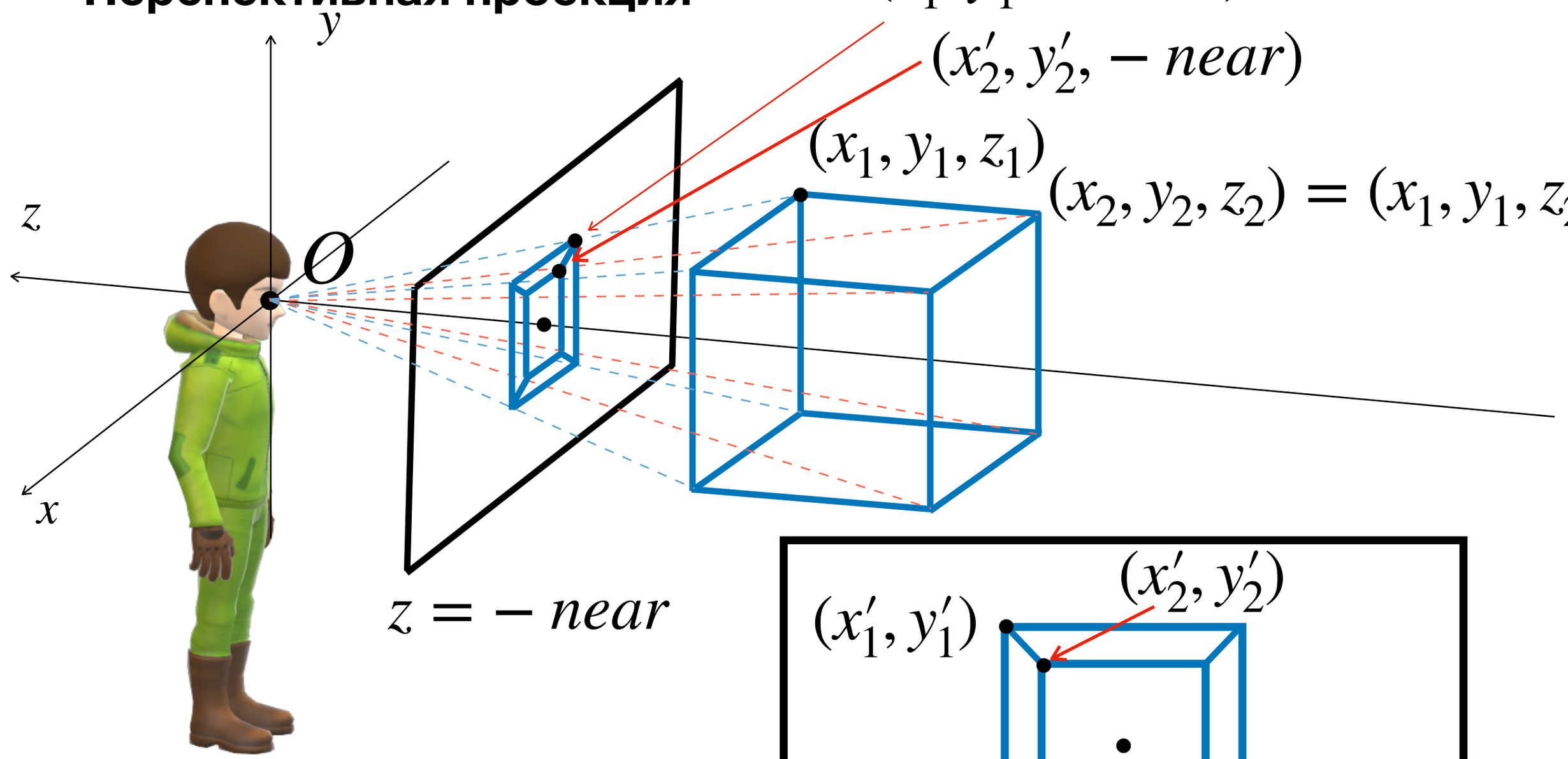
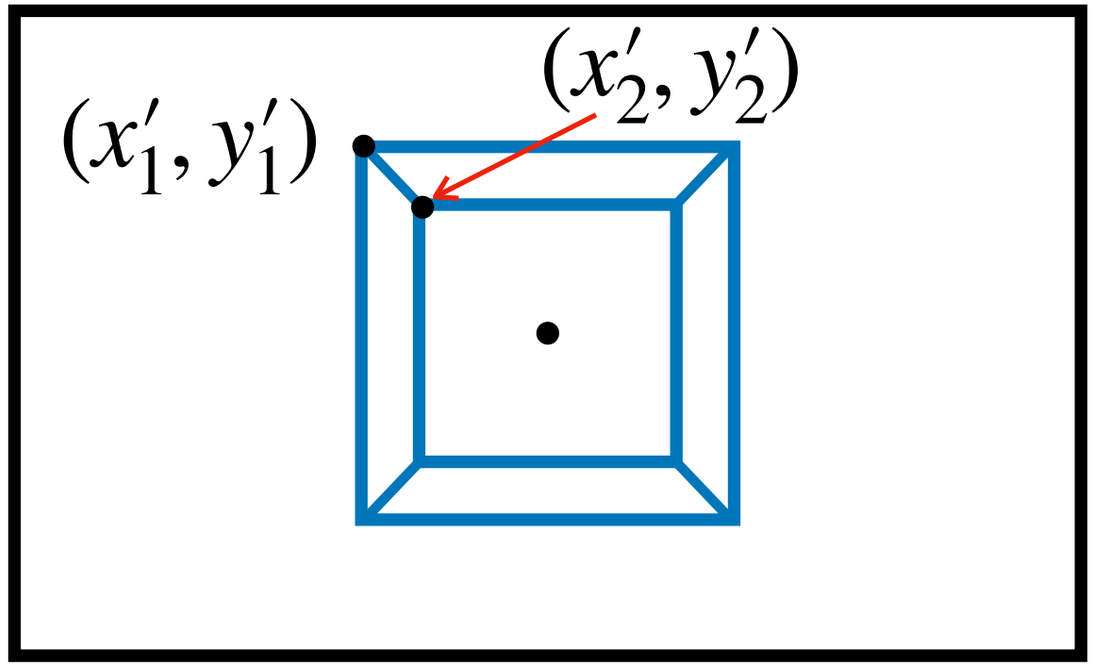
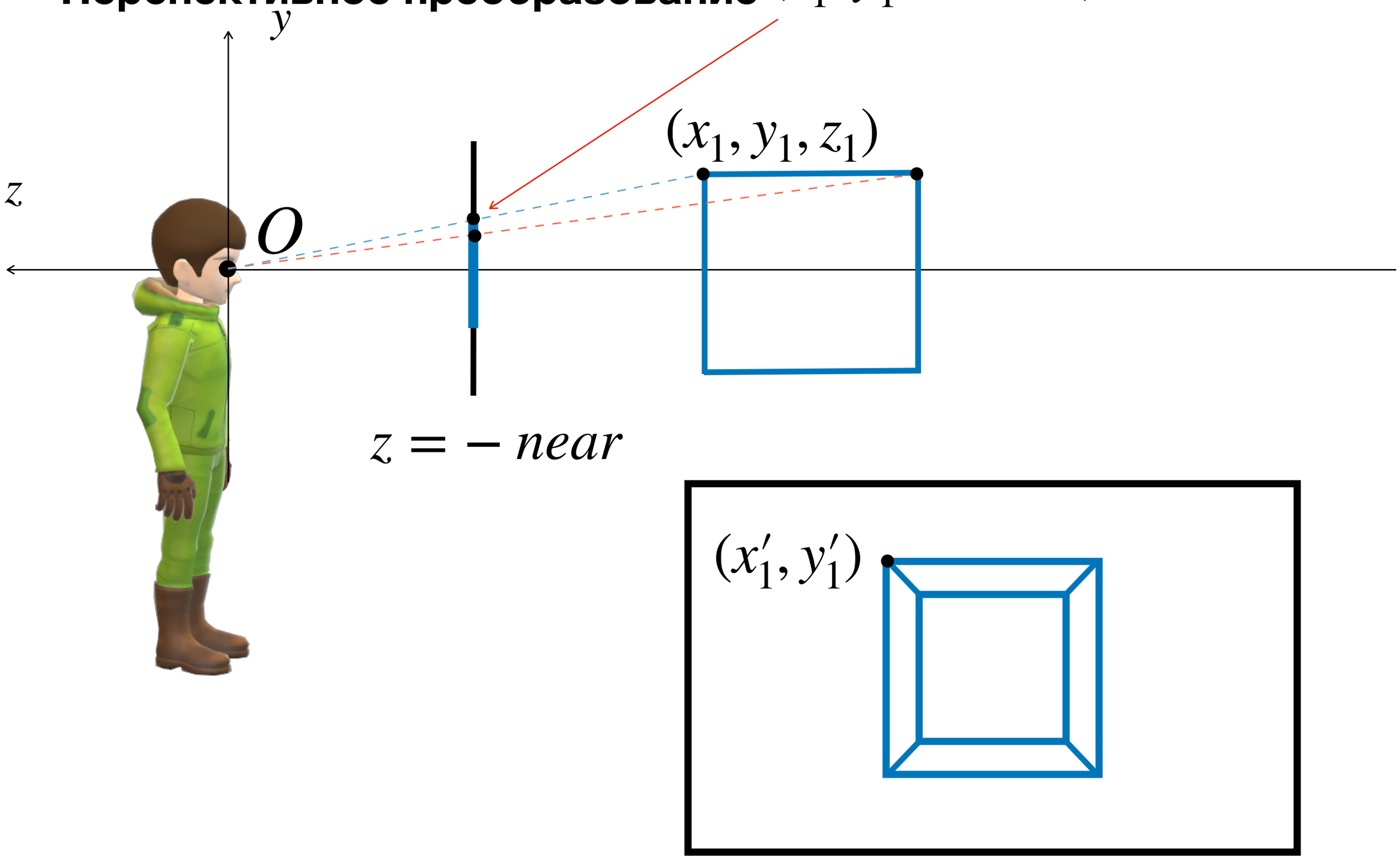
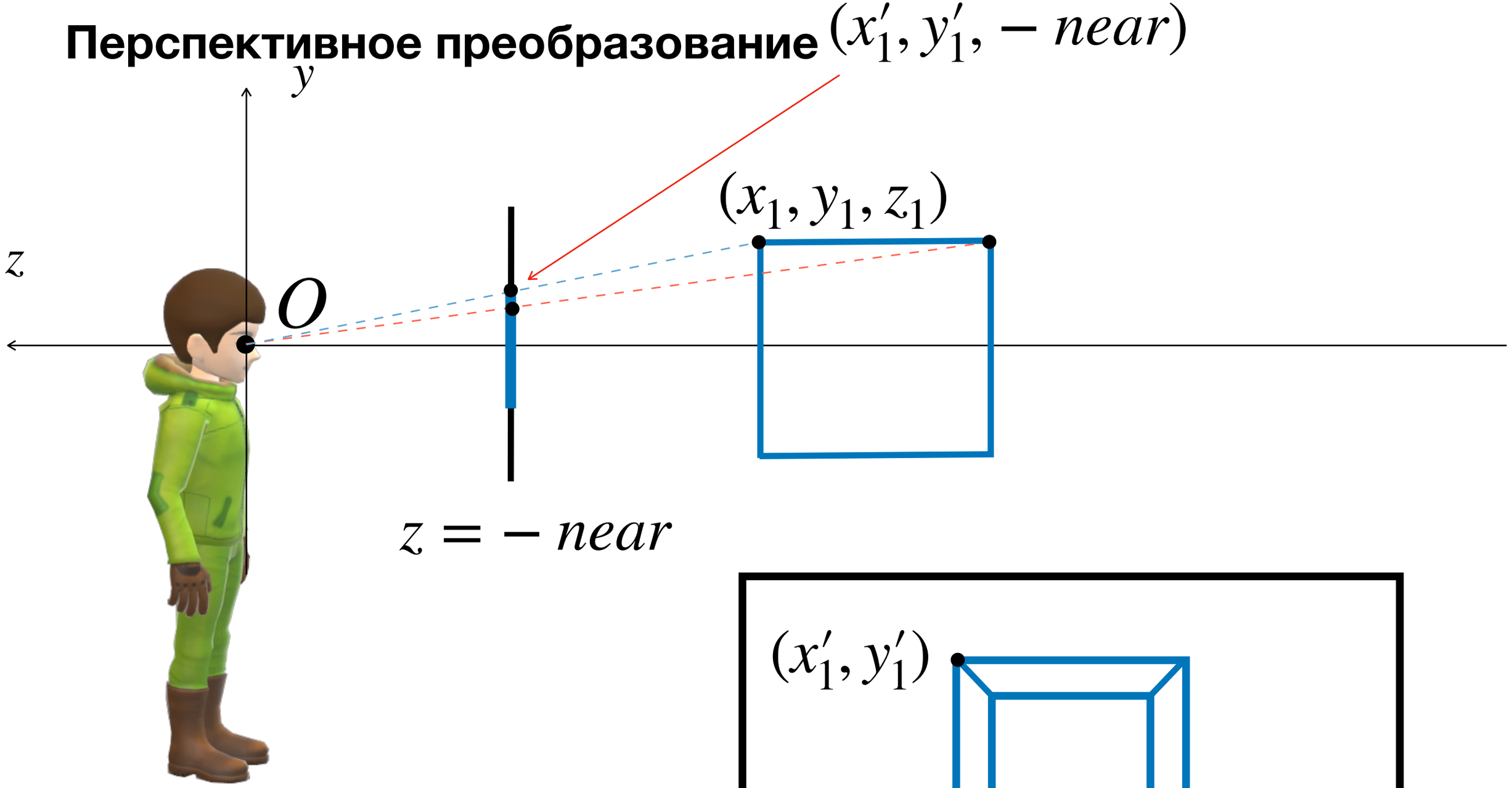




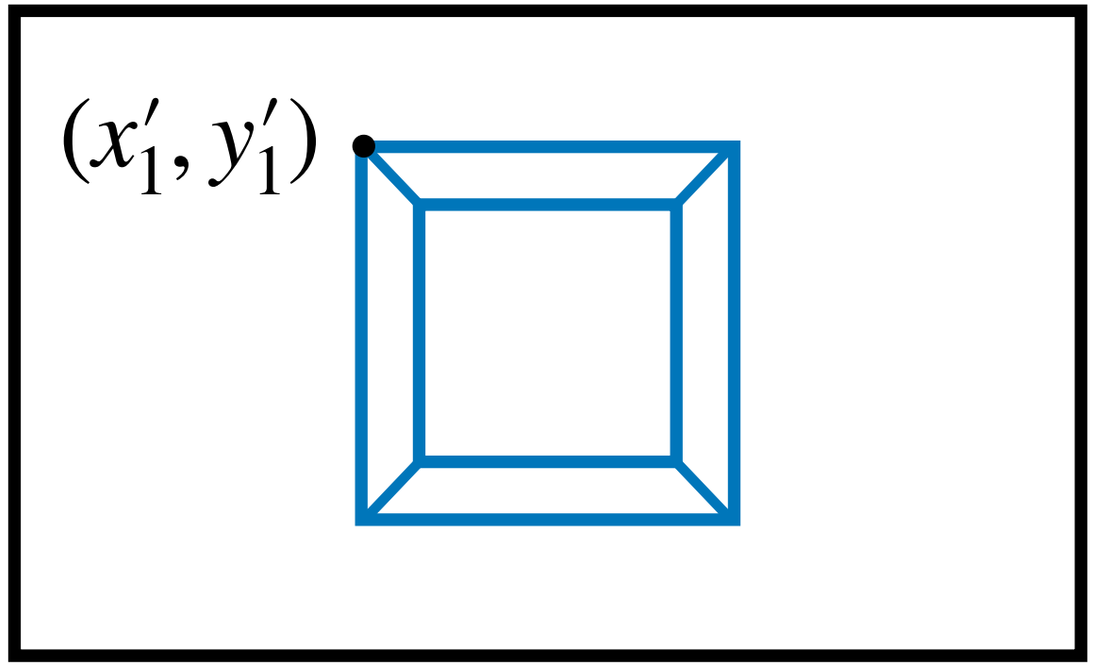
Перспективное преобразование



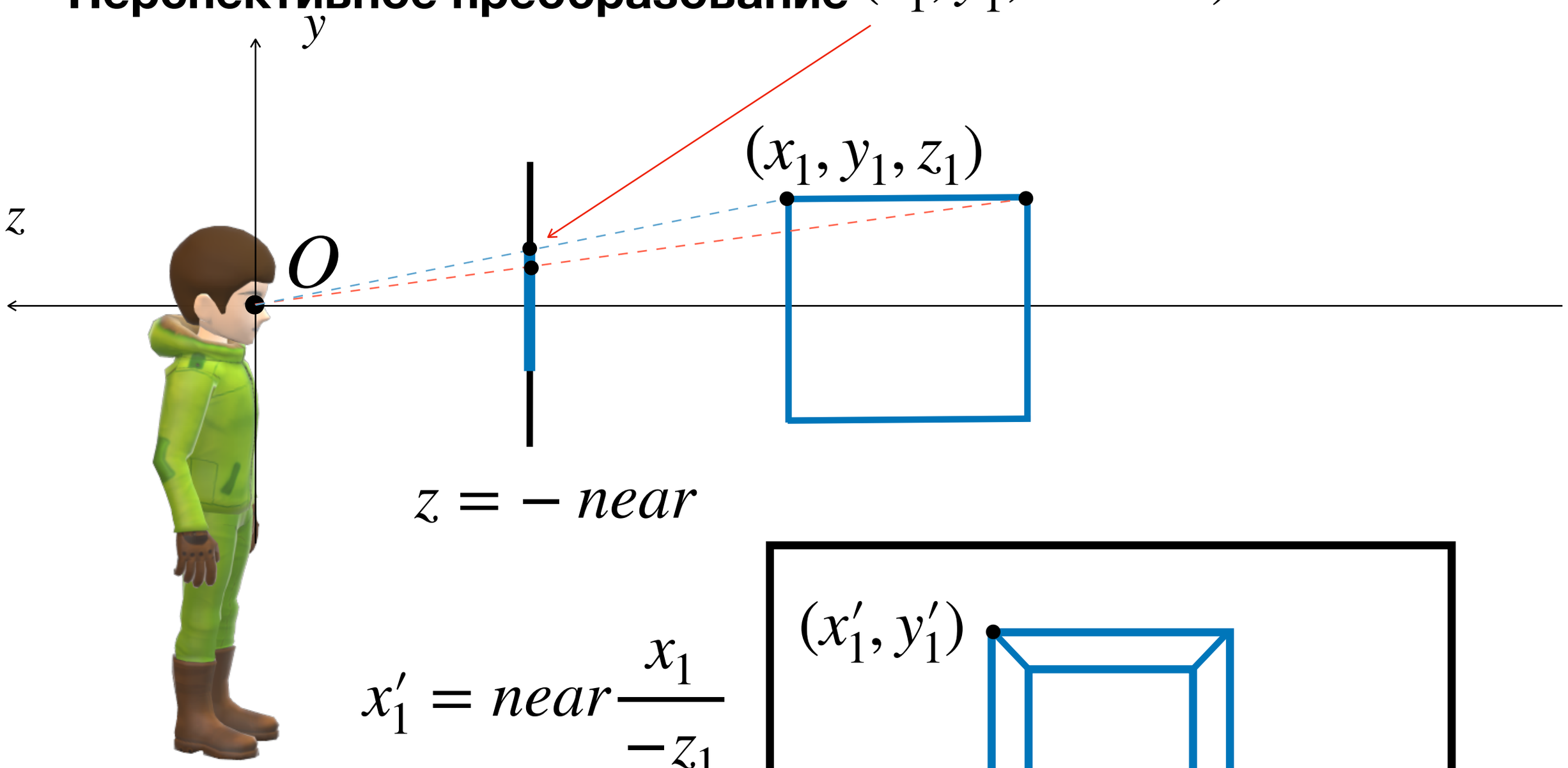
Перспективное преобразование



$$\frac{y_1'}{near} = \frac{y_1}{-z_1}$$

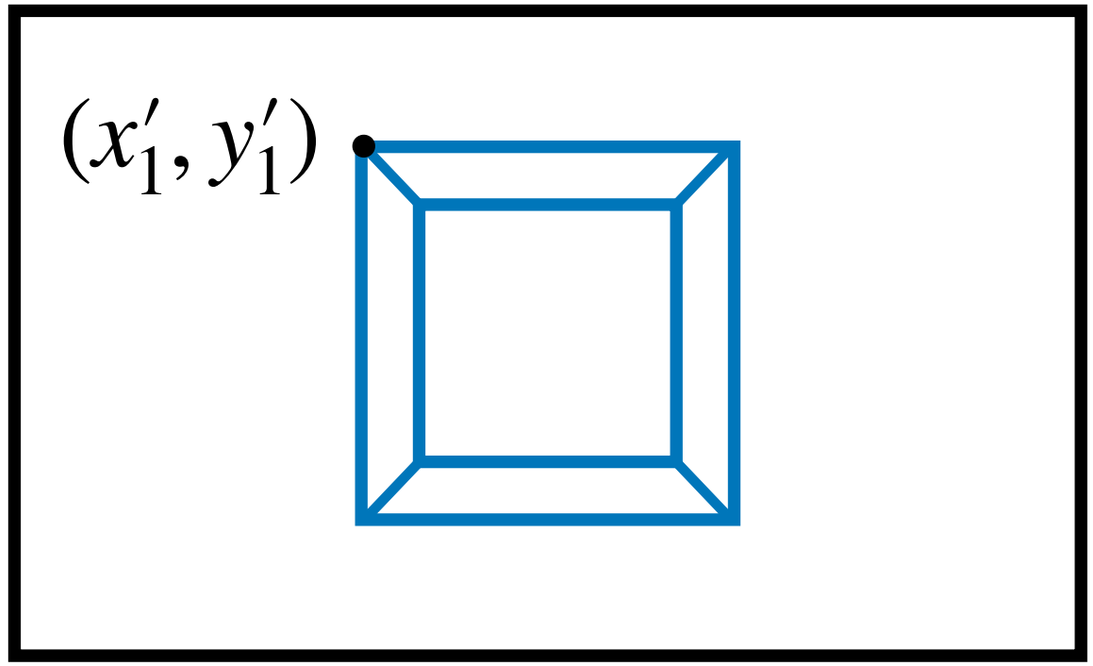


Перспективное преобразование

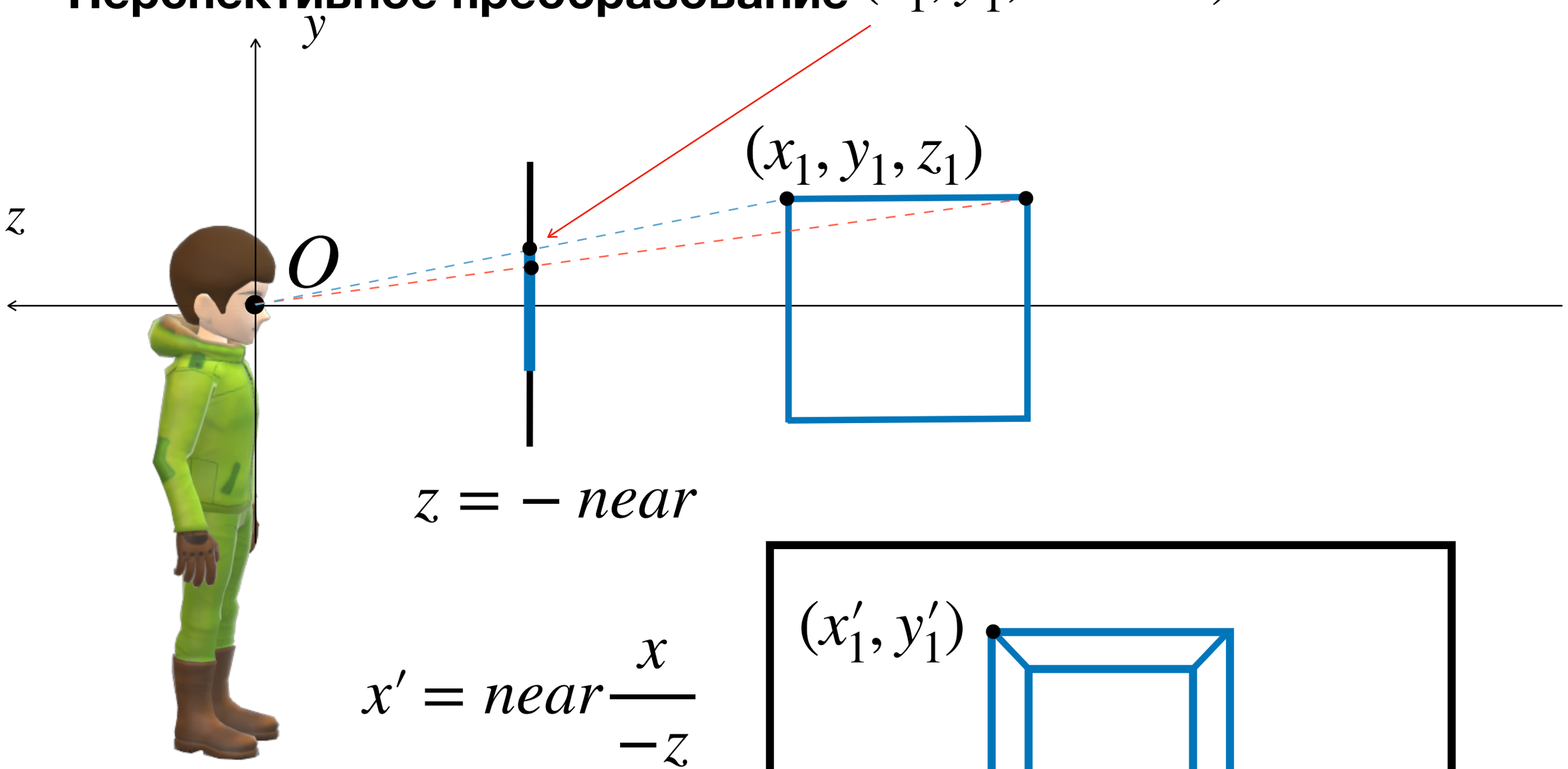


$$x_1' = near\frac{x_1}{-z_1}$$

$$y_1' = near\frac{y_1}{-z_1}$$

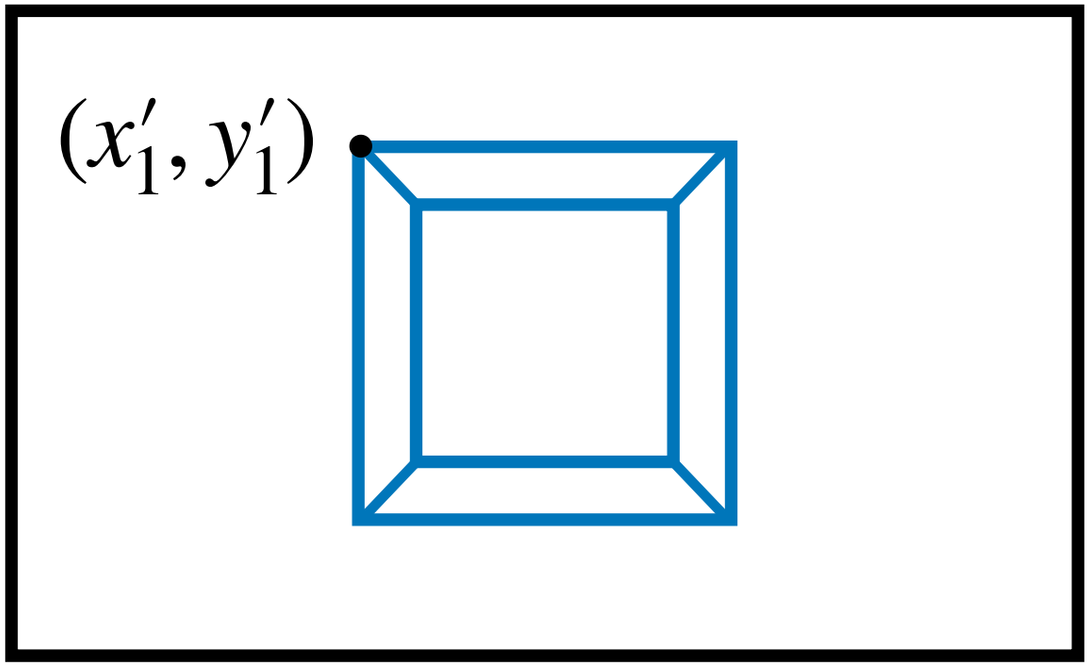


Перспективное преобразование



$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$



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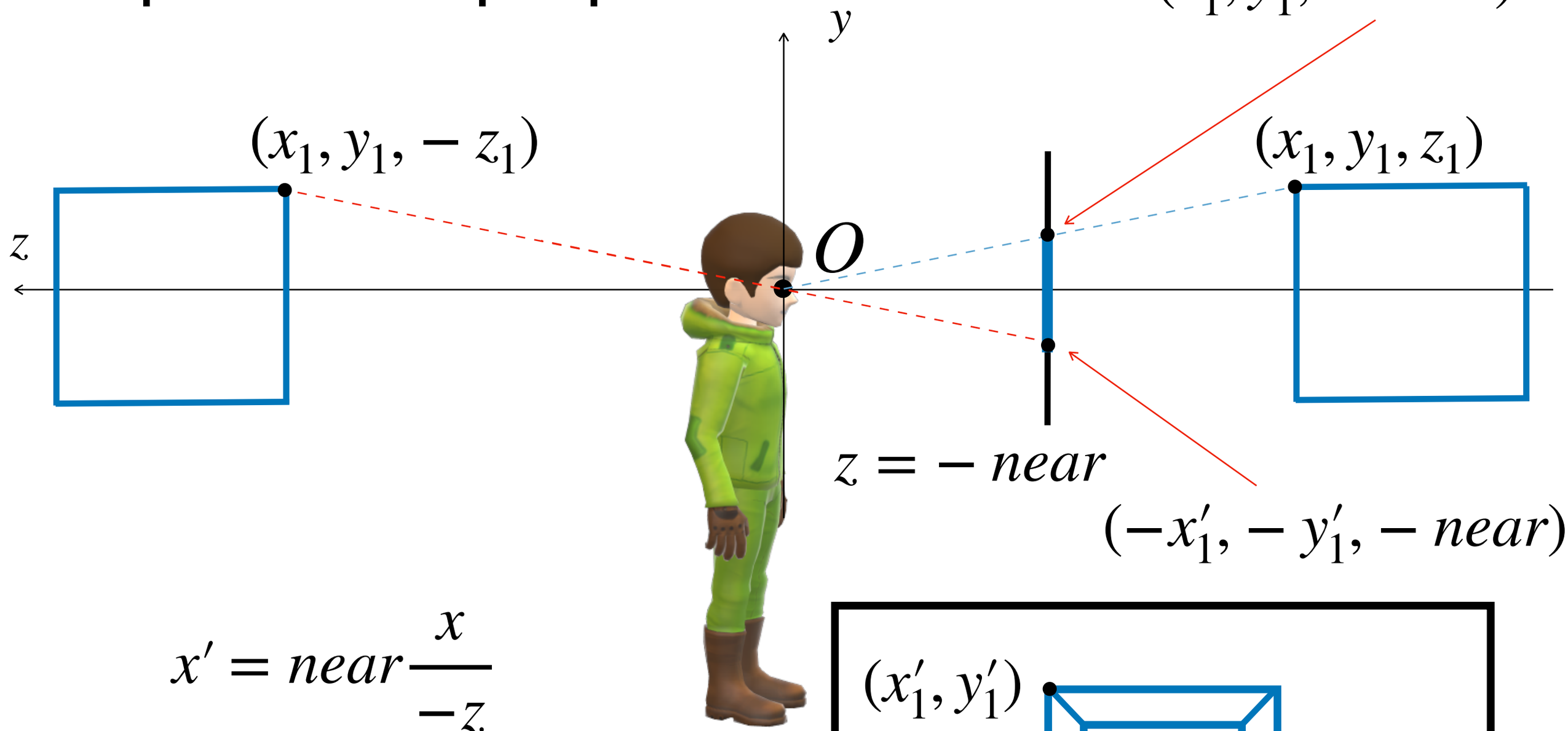
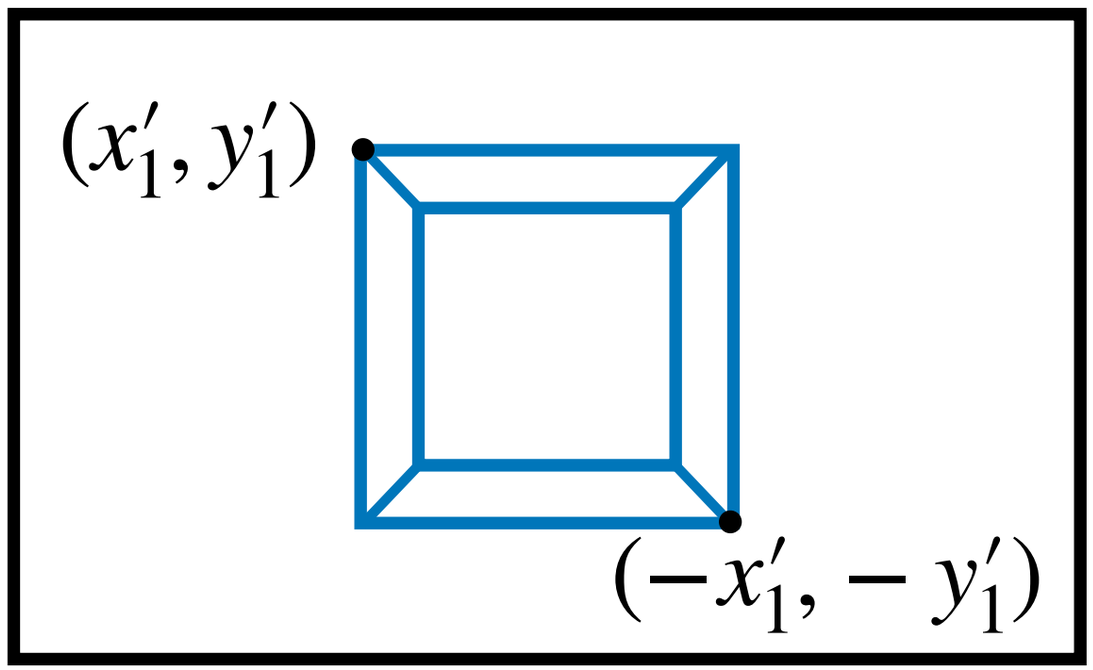


$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$



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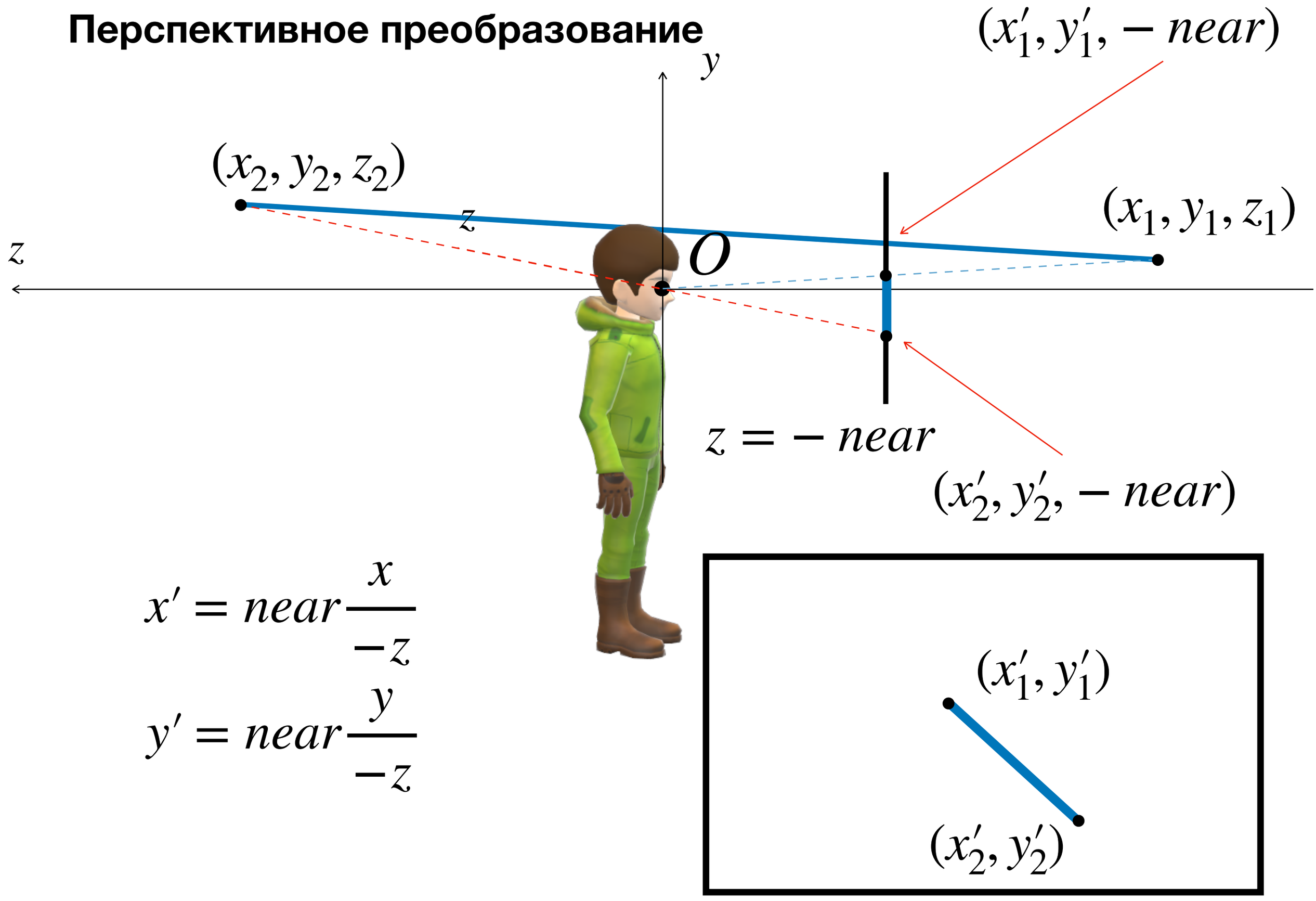
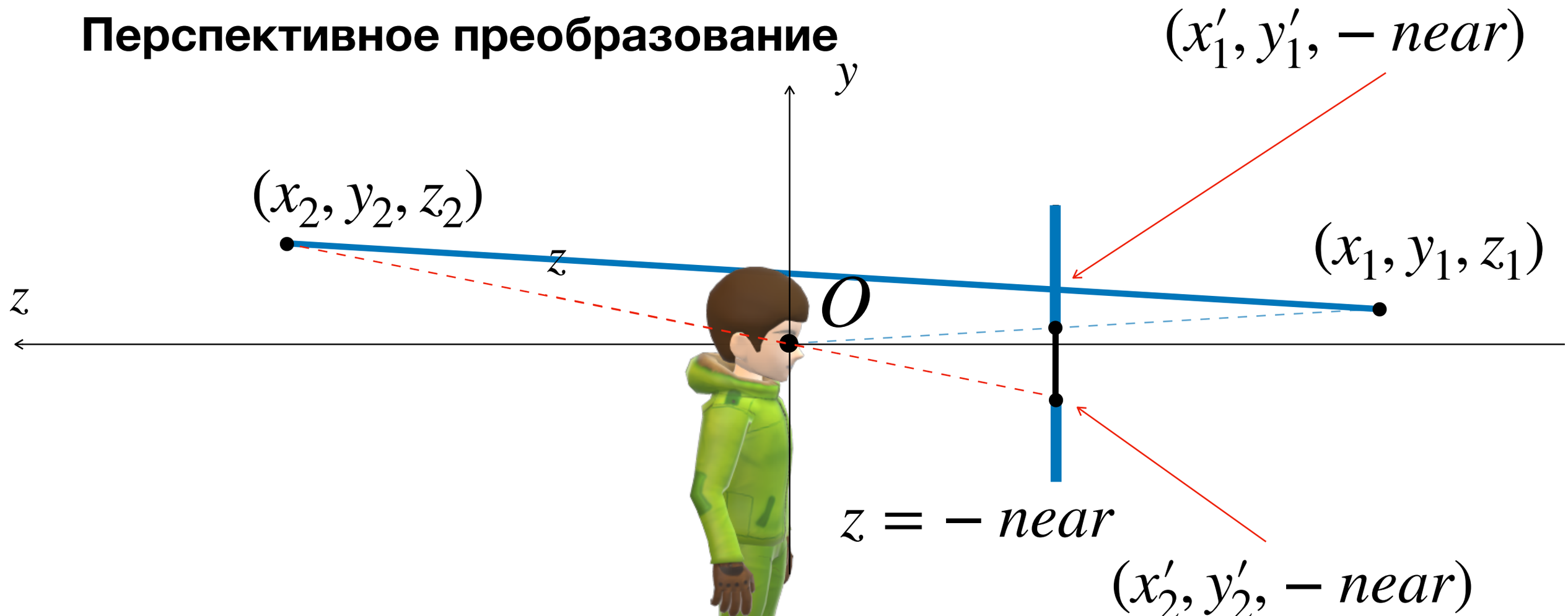


$$x' = near\frac{x}{-z}$$

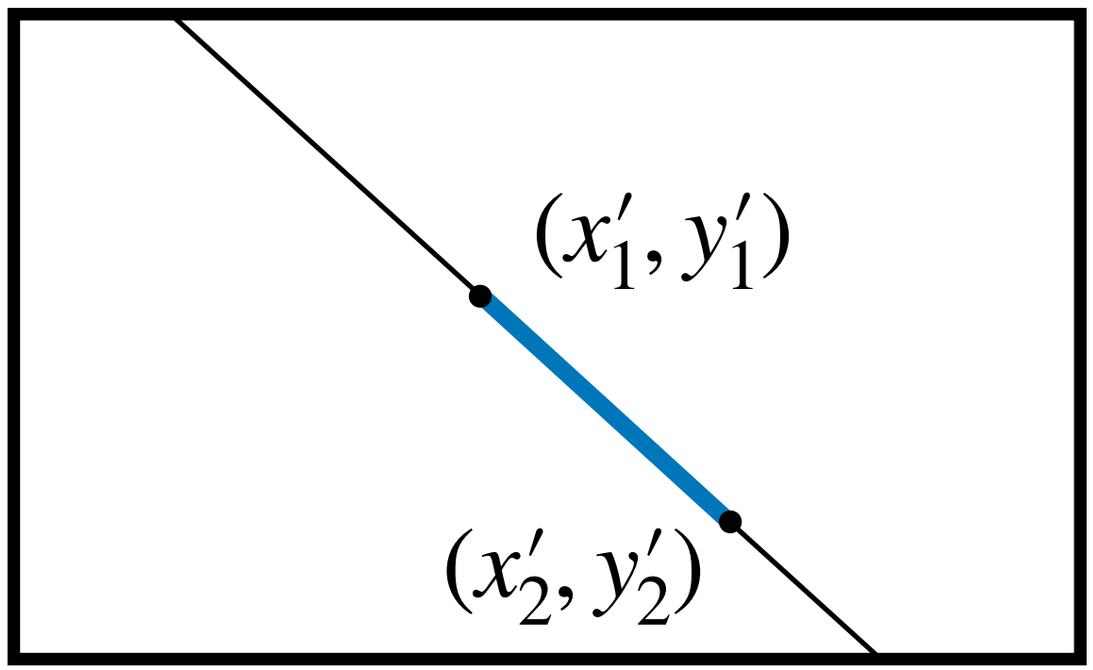
$$y' = near\frac{y}{-z}$$

Перспективное преобразование



$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$



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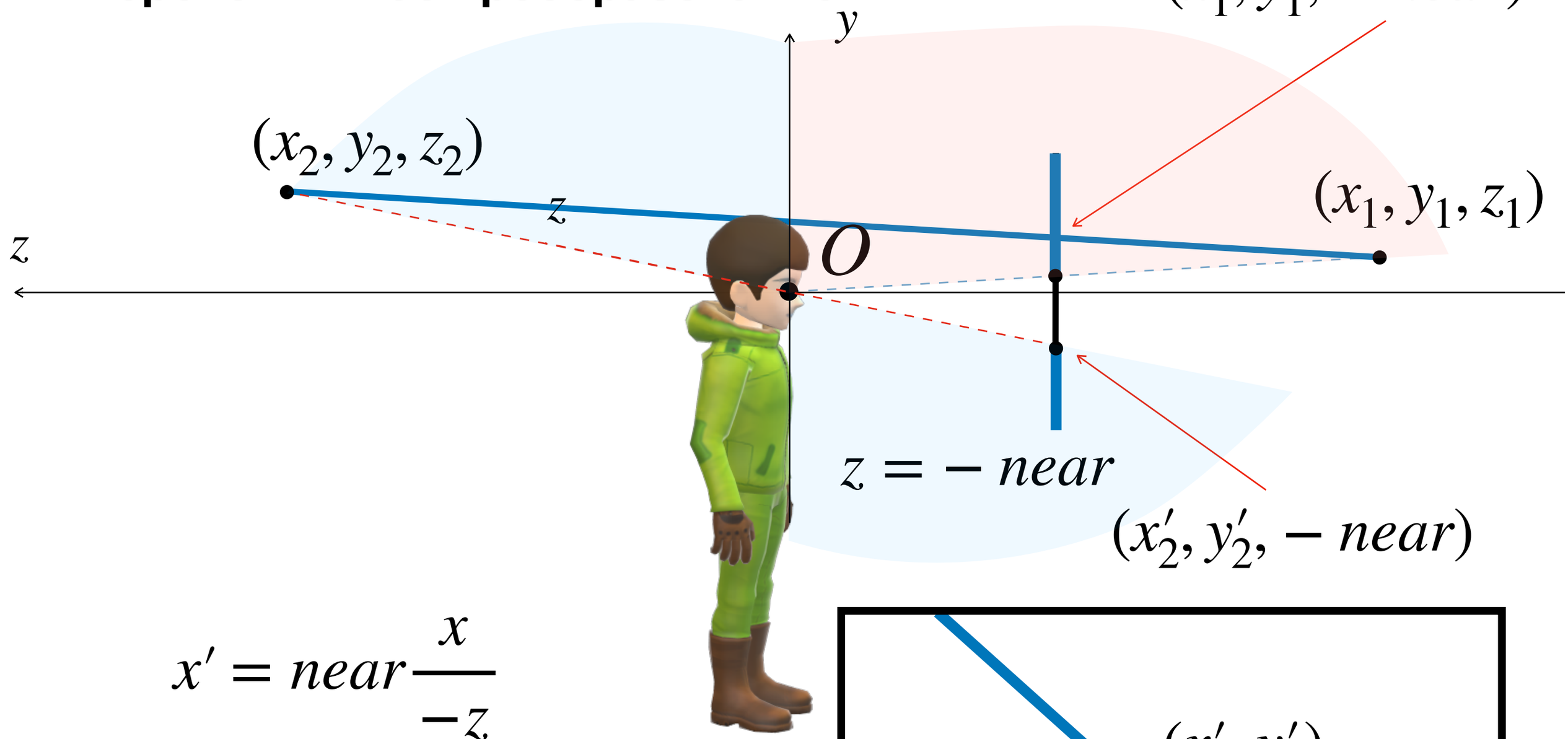
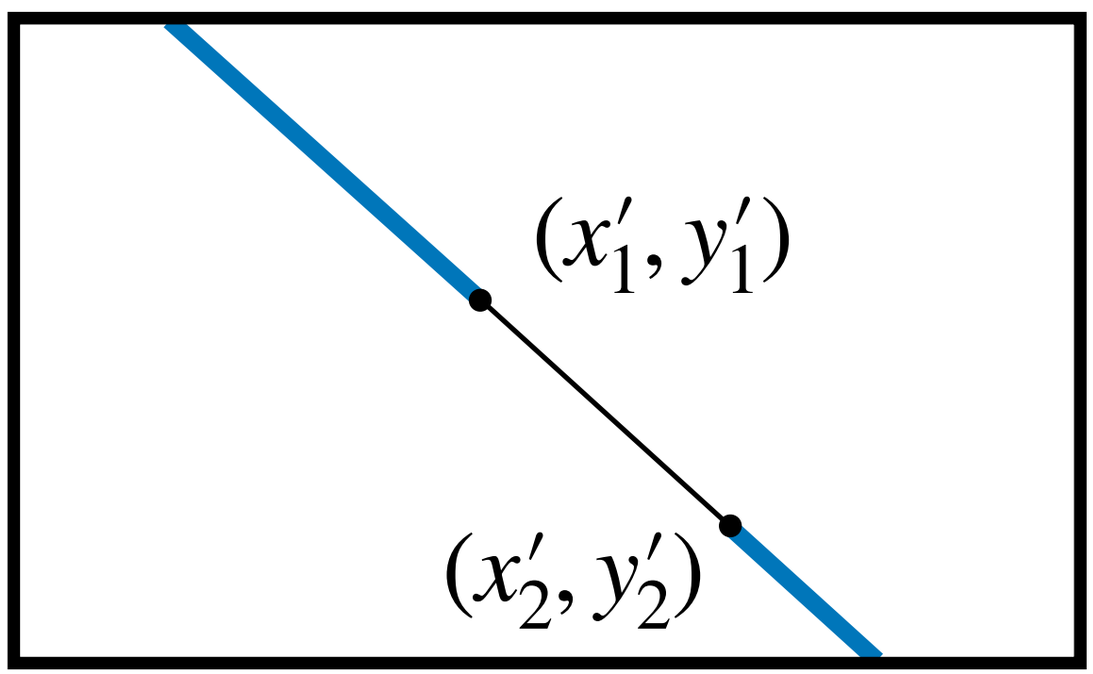


$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$



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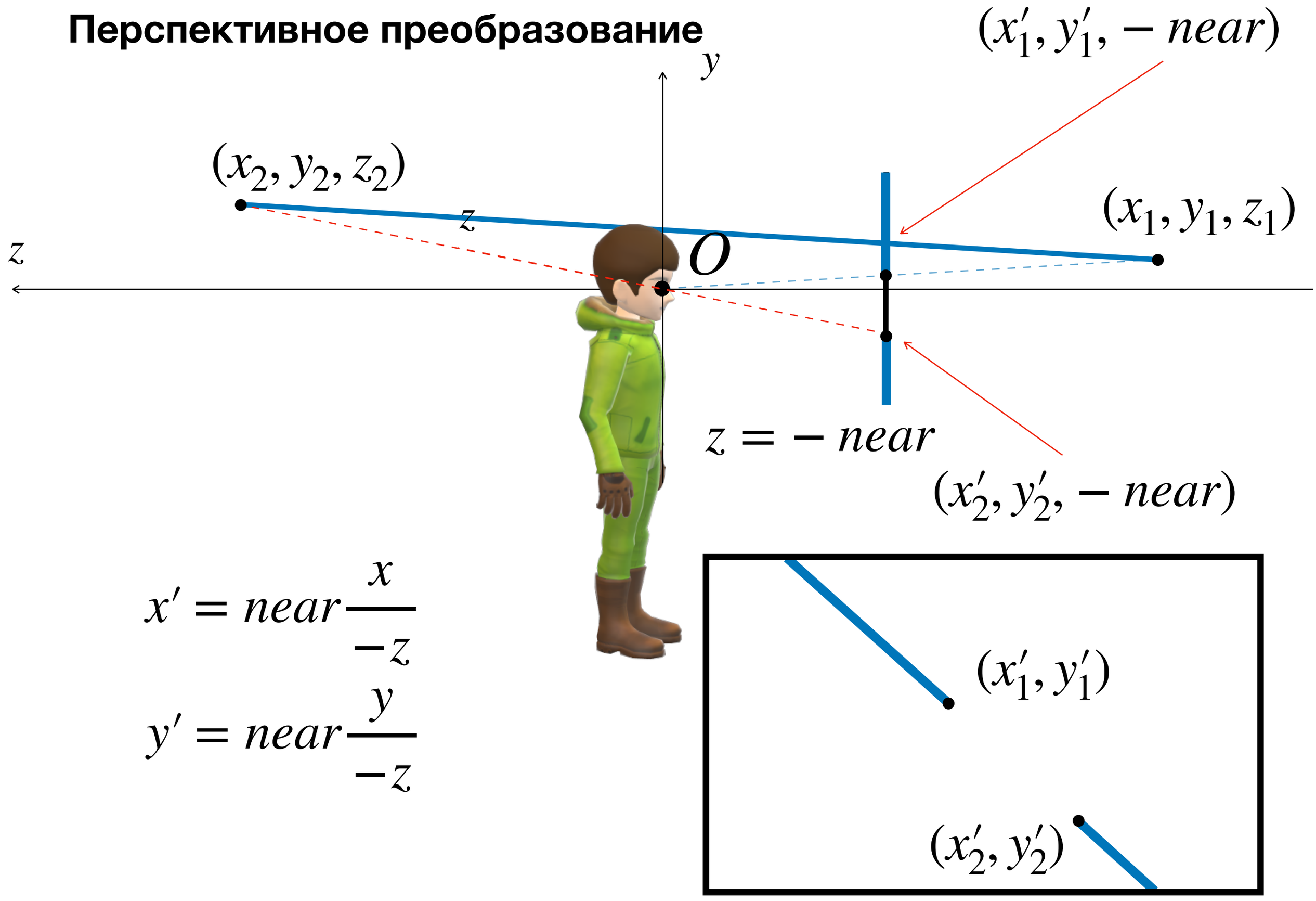
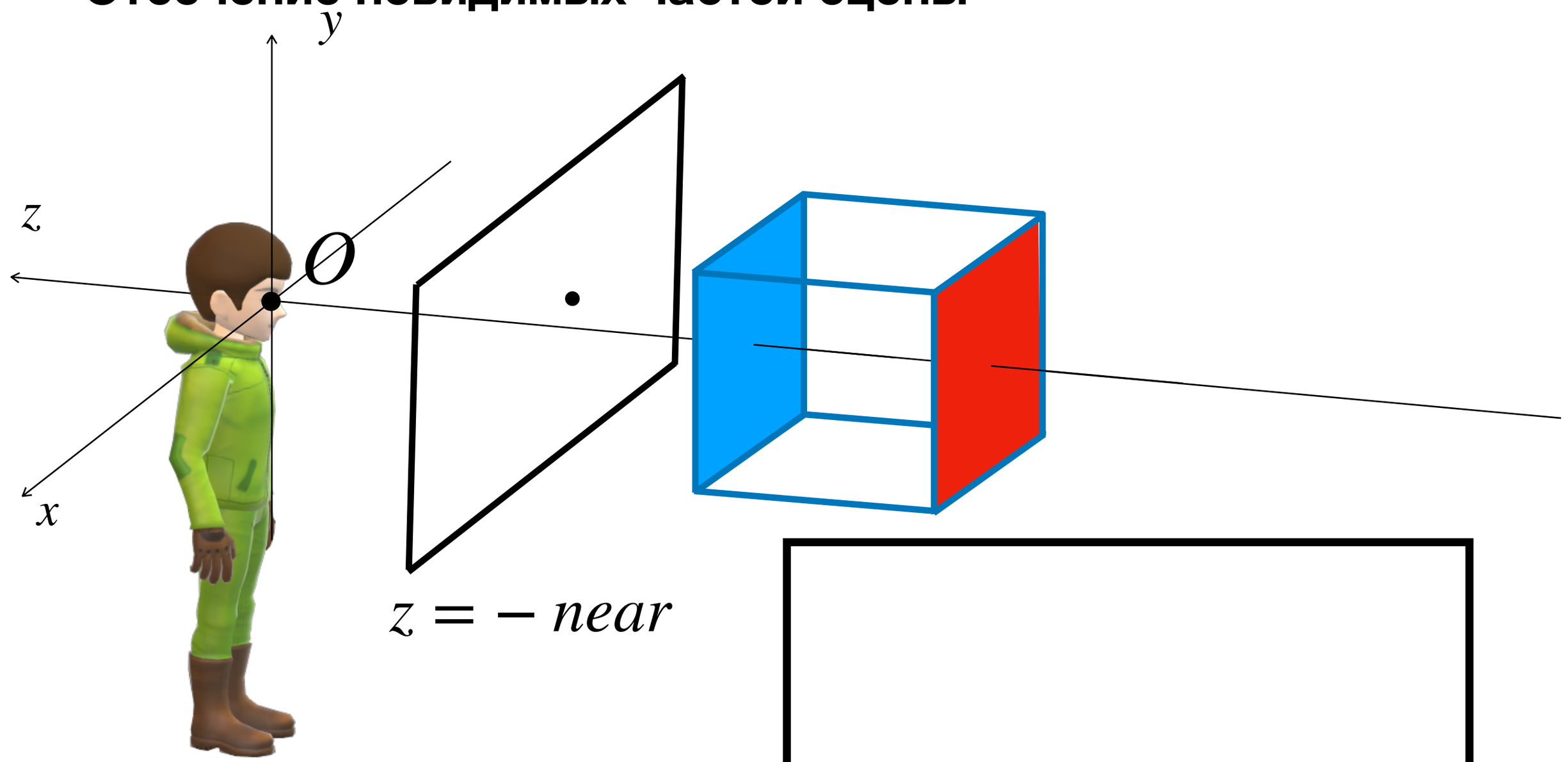


$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$

Отсечение невидимых частей сцены



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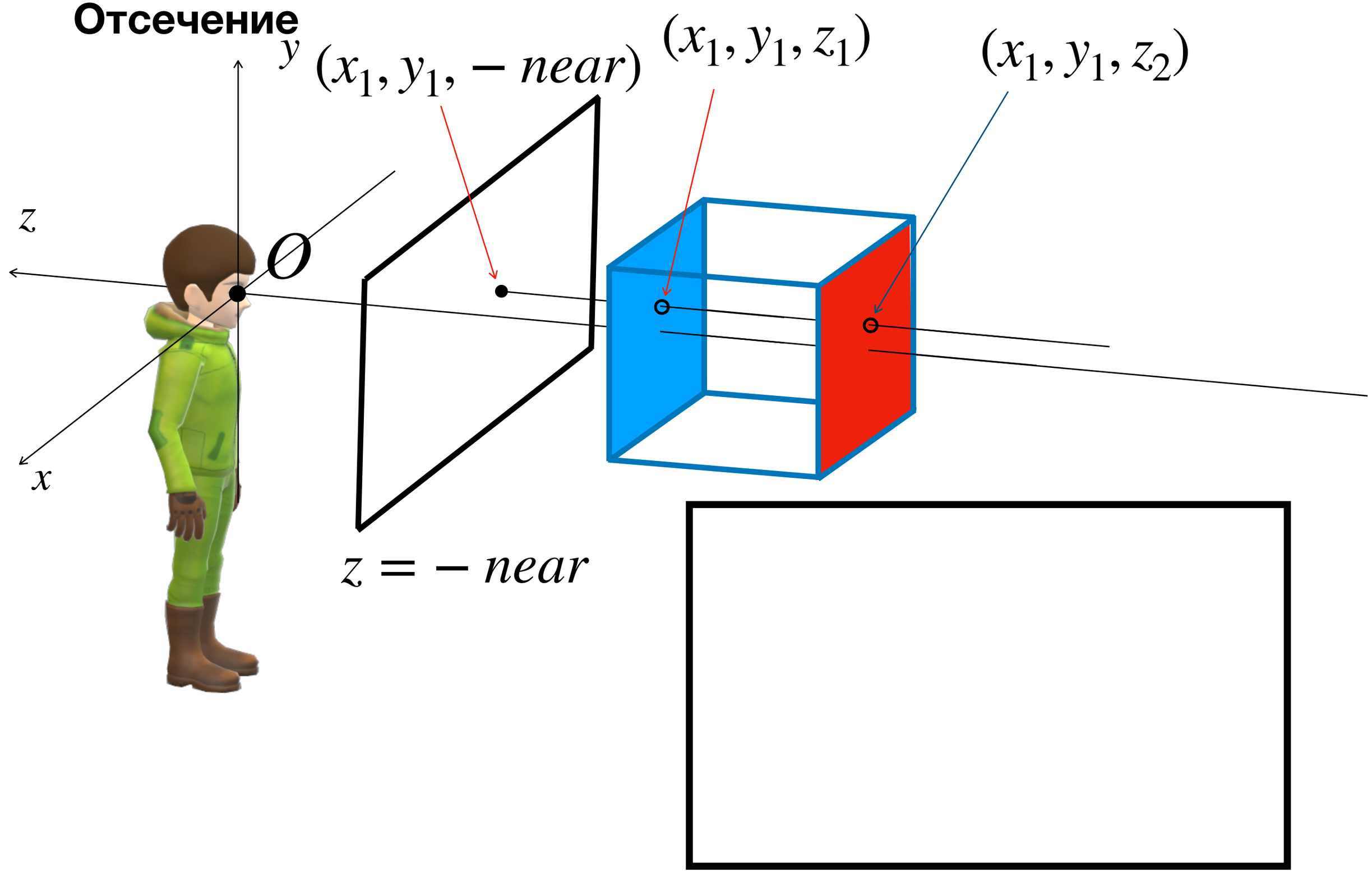
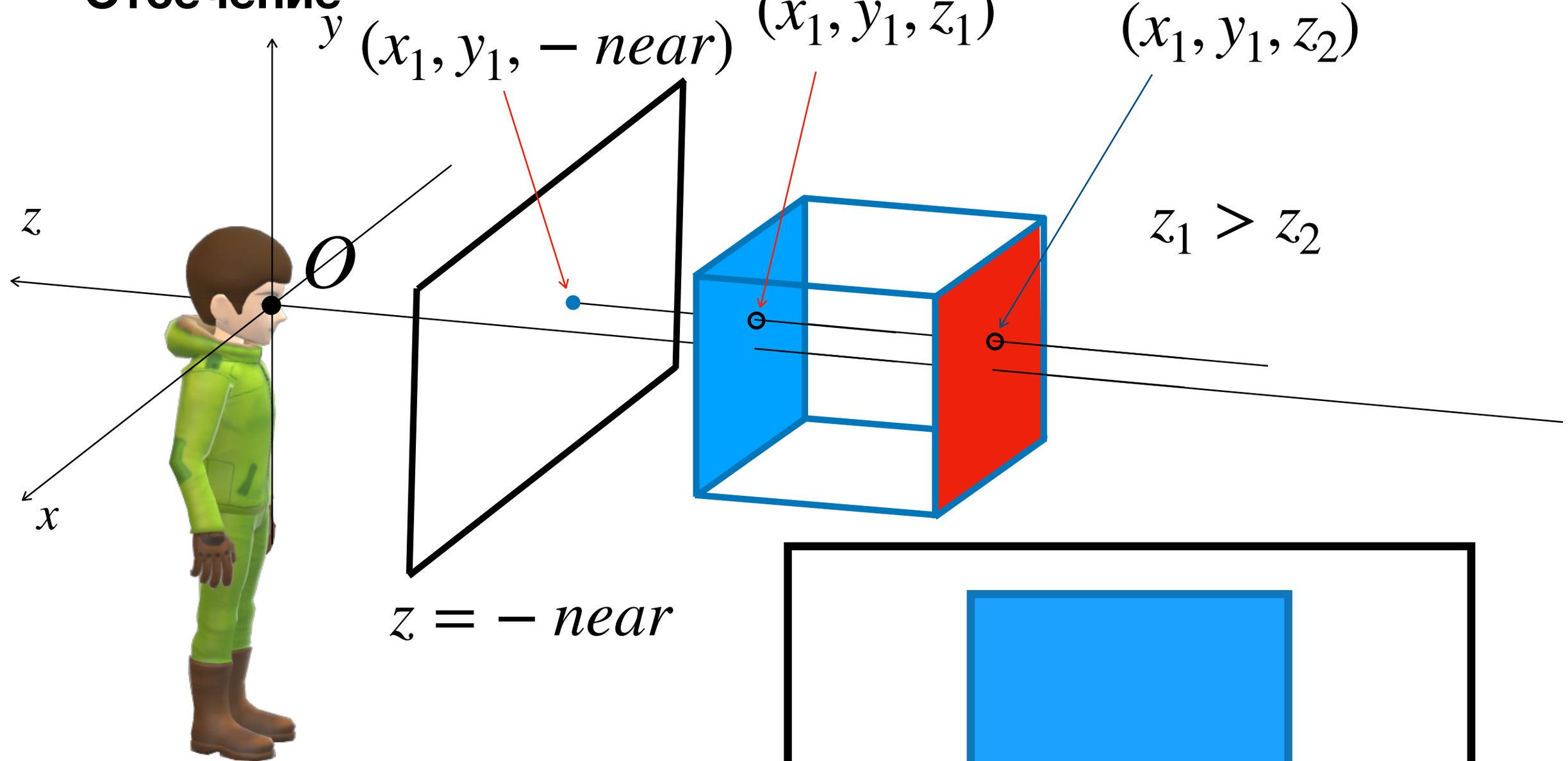
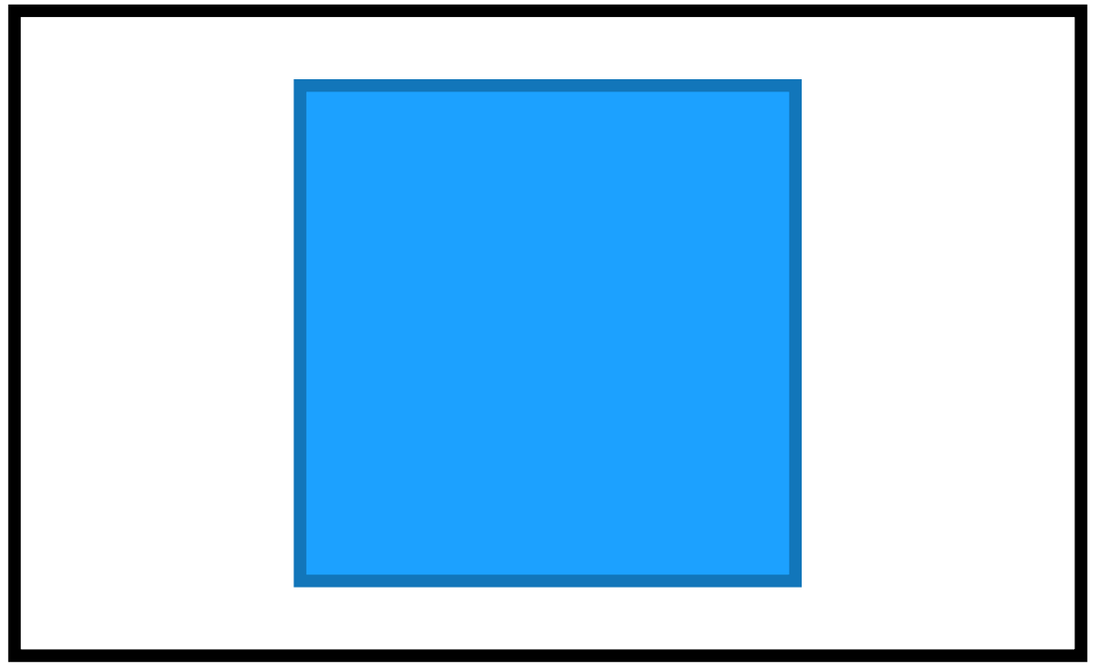


Отсечение





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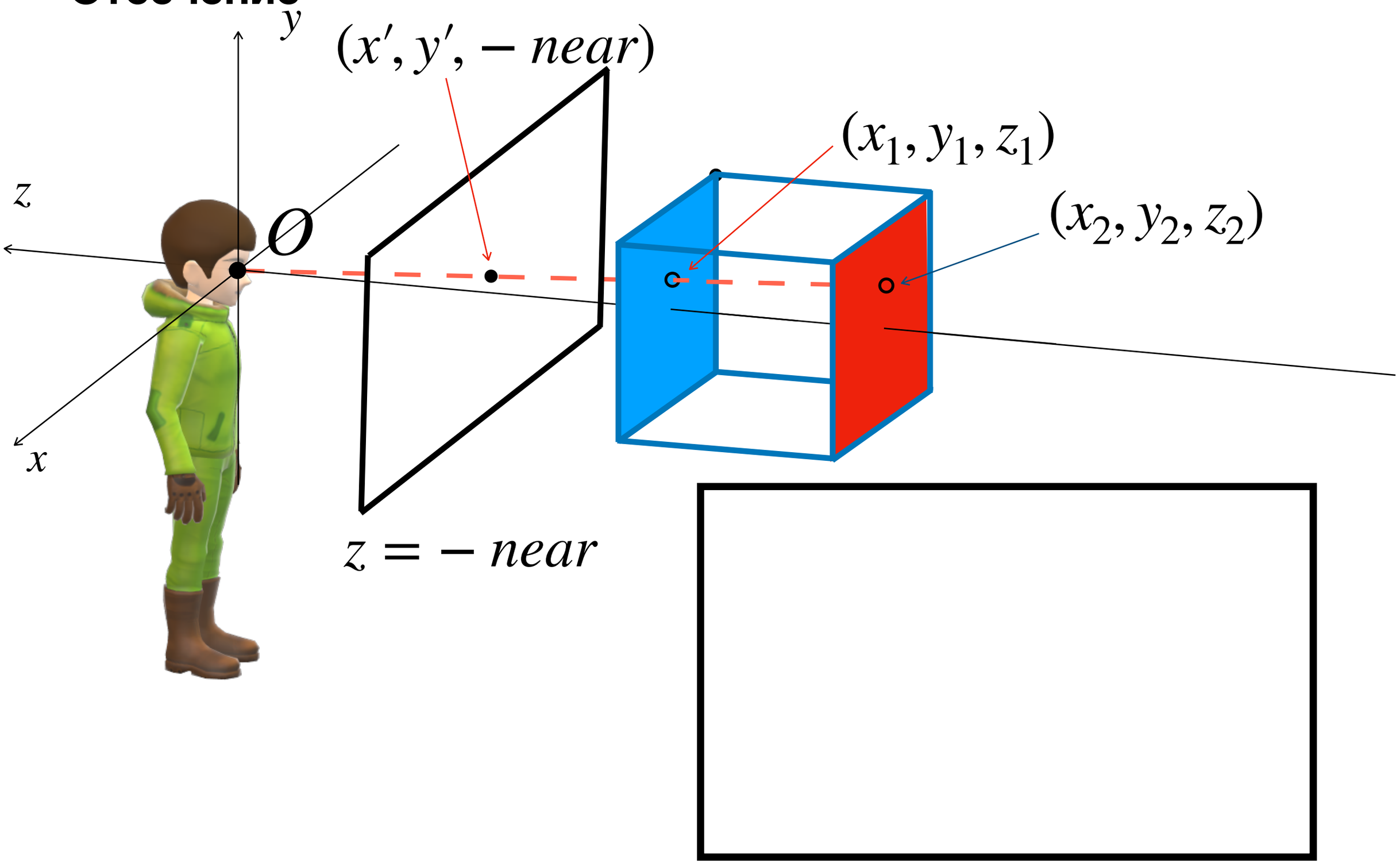

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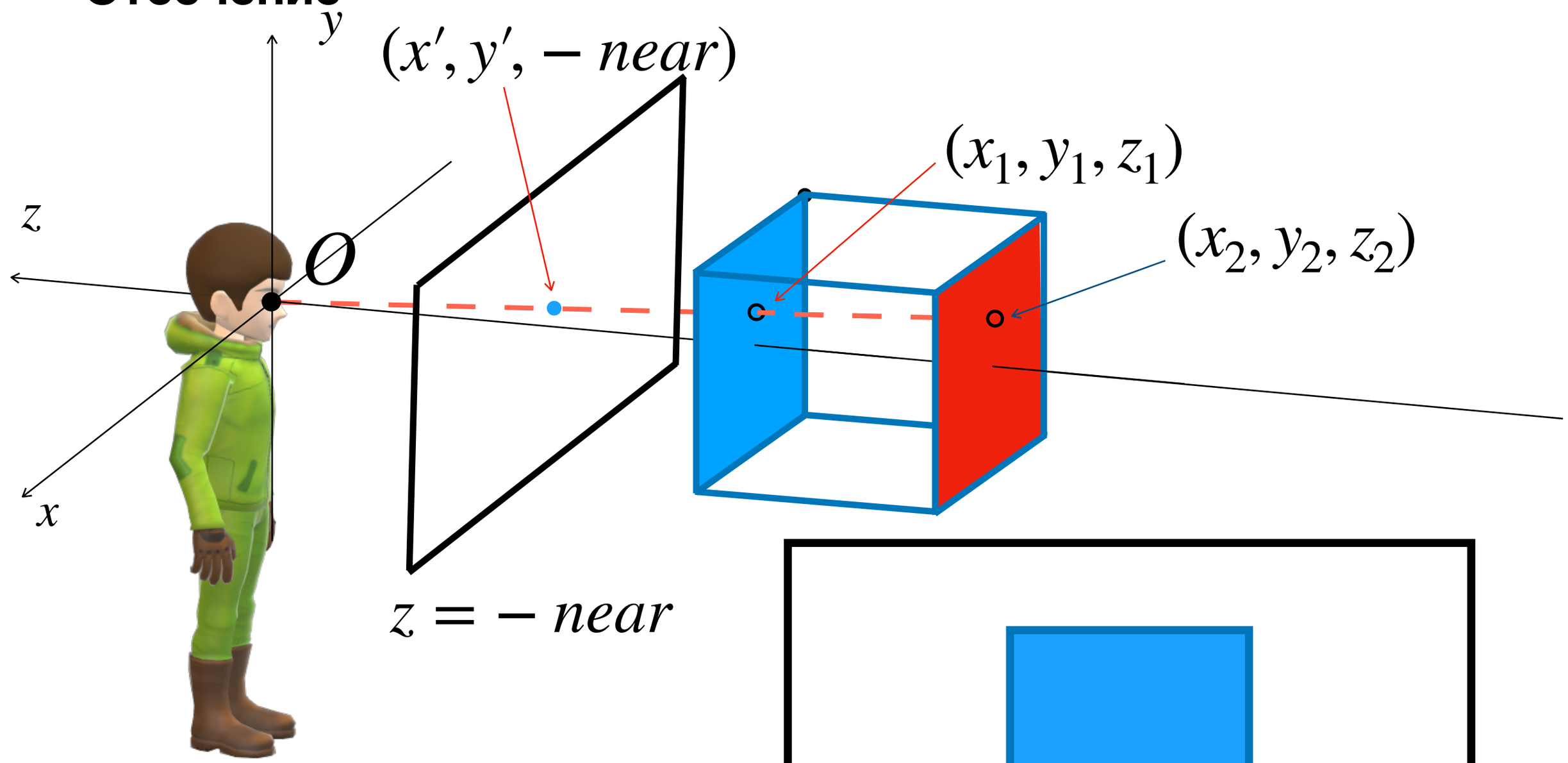
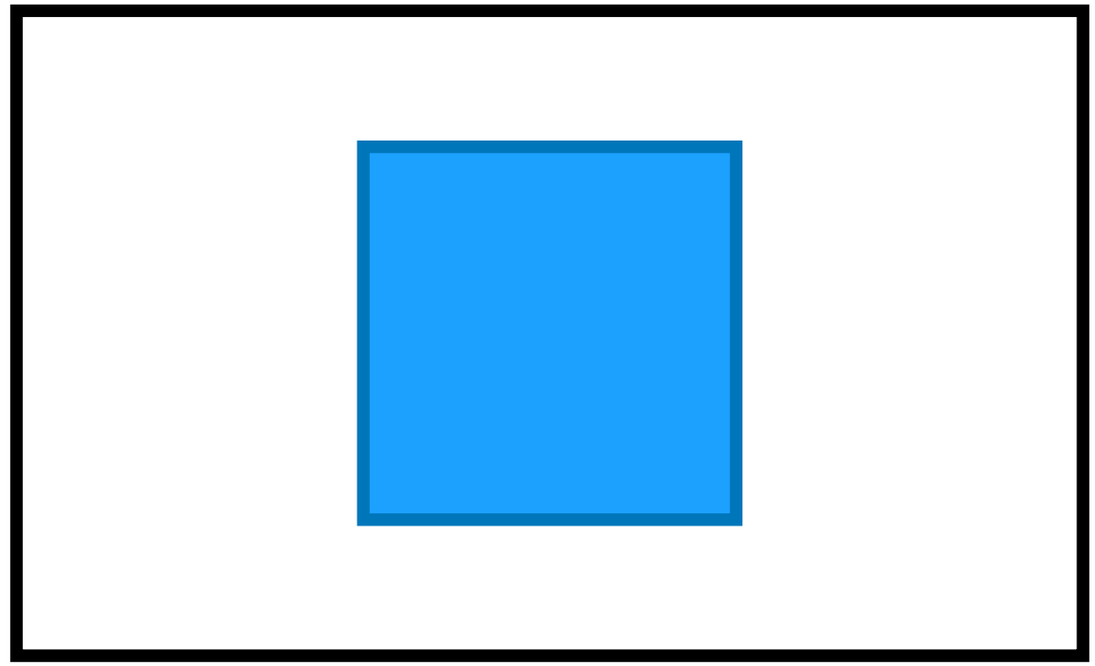
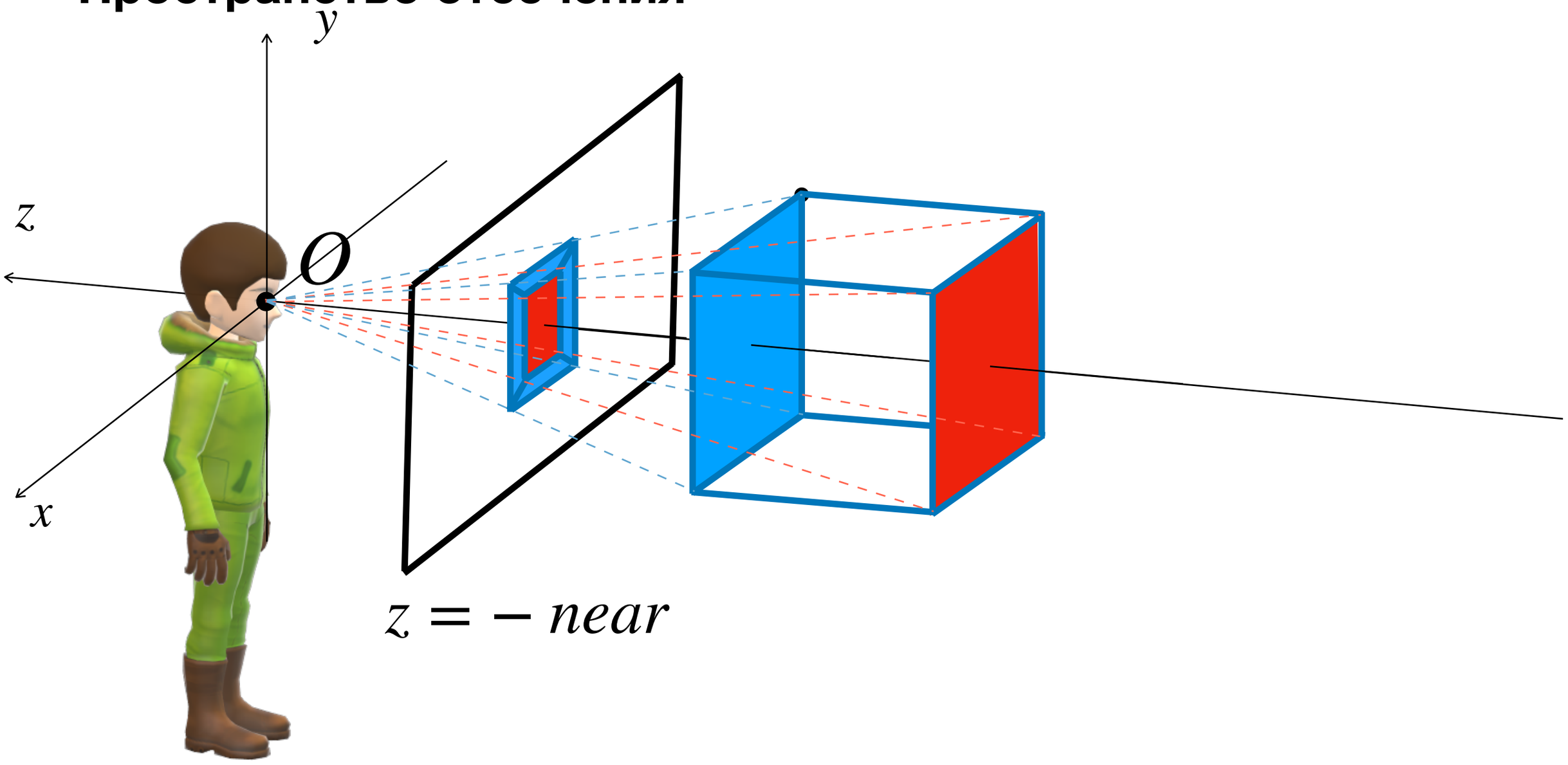
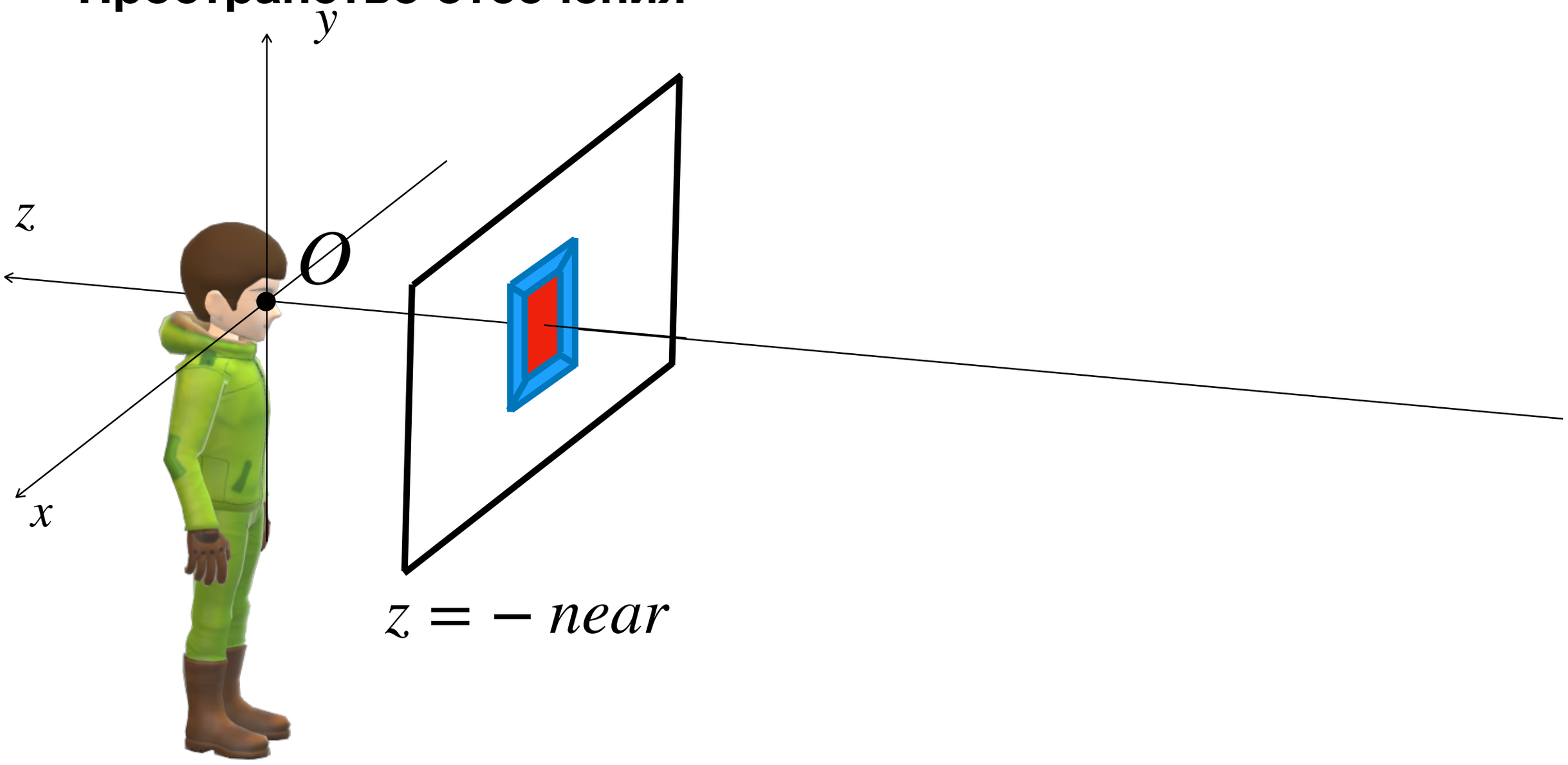




Пространство отсечения



Пространство отсечения



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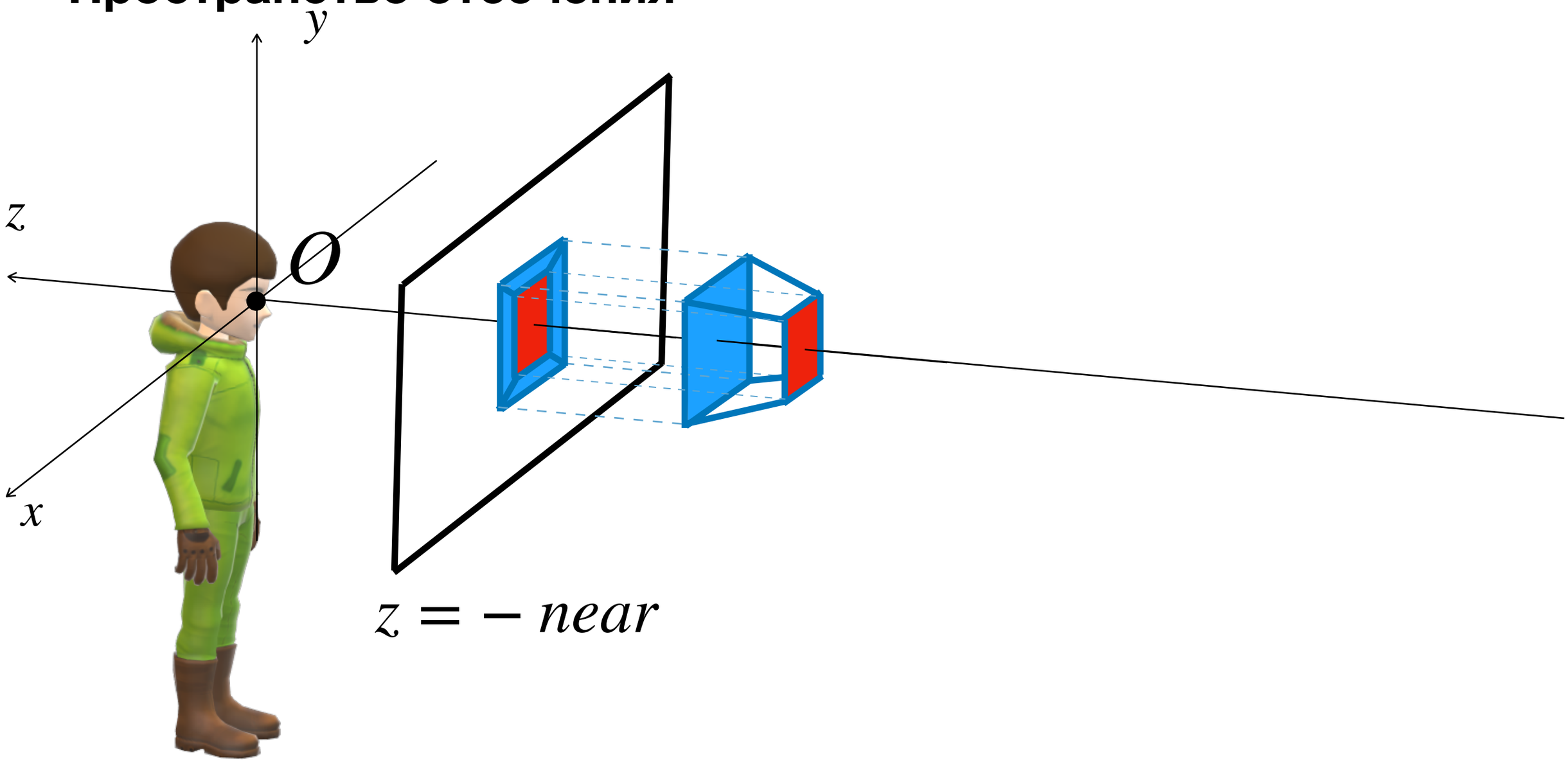
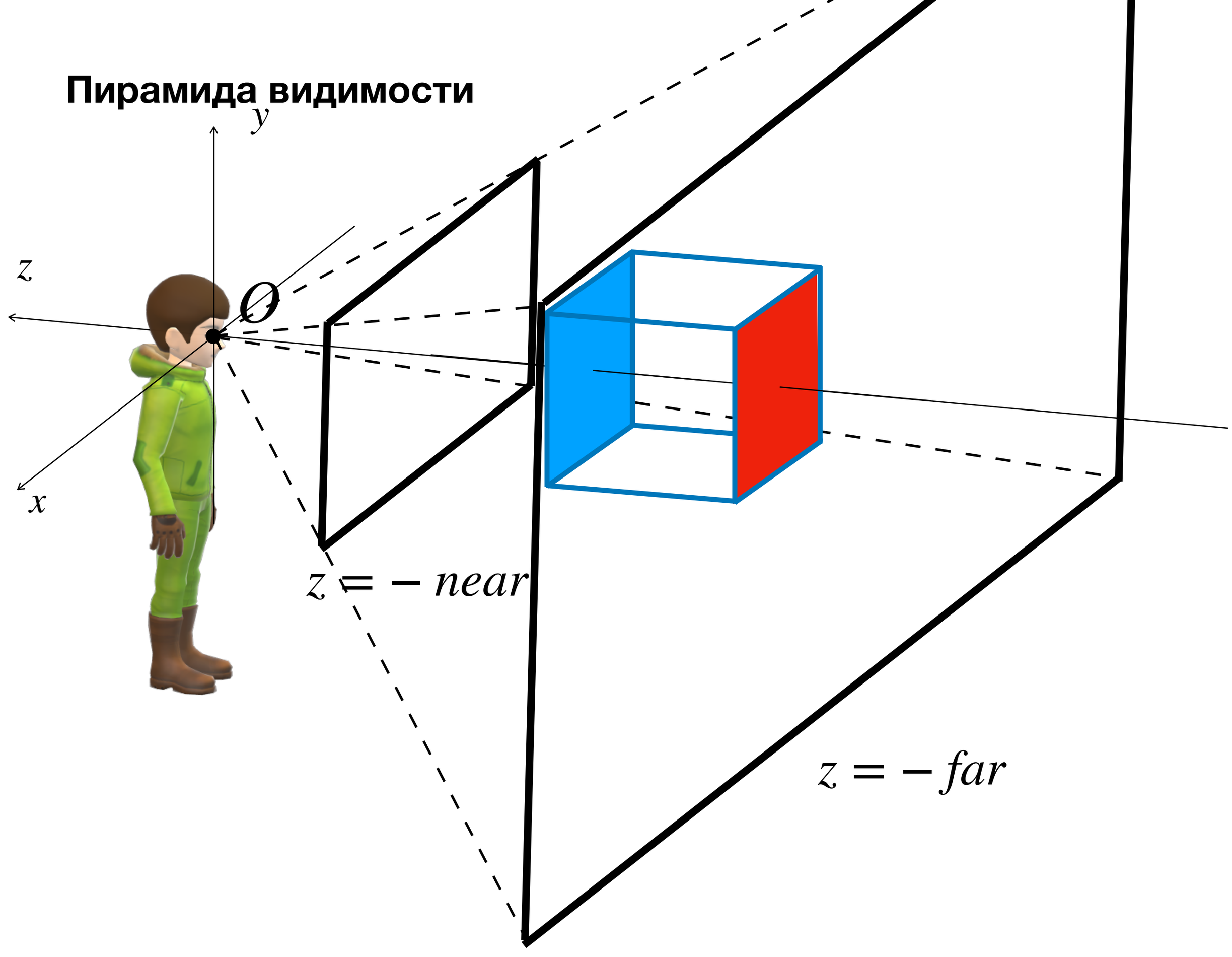


Пирамида видимости



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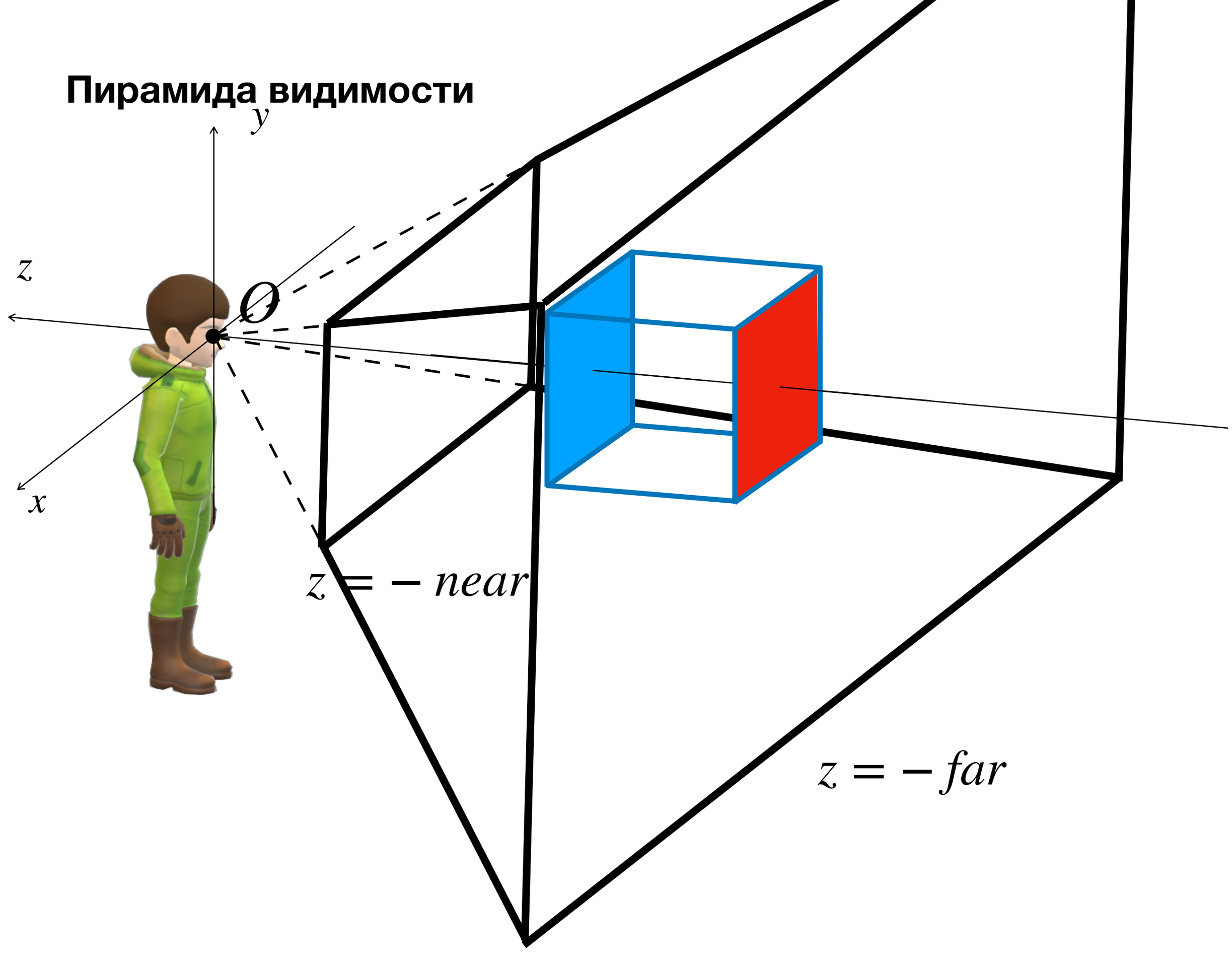
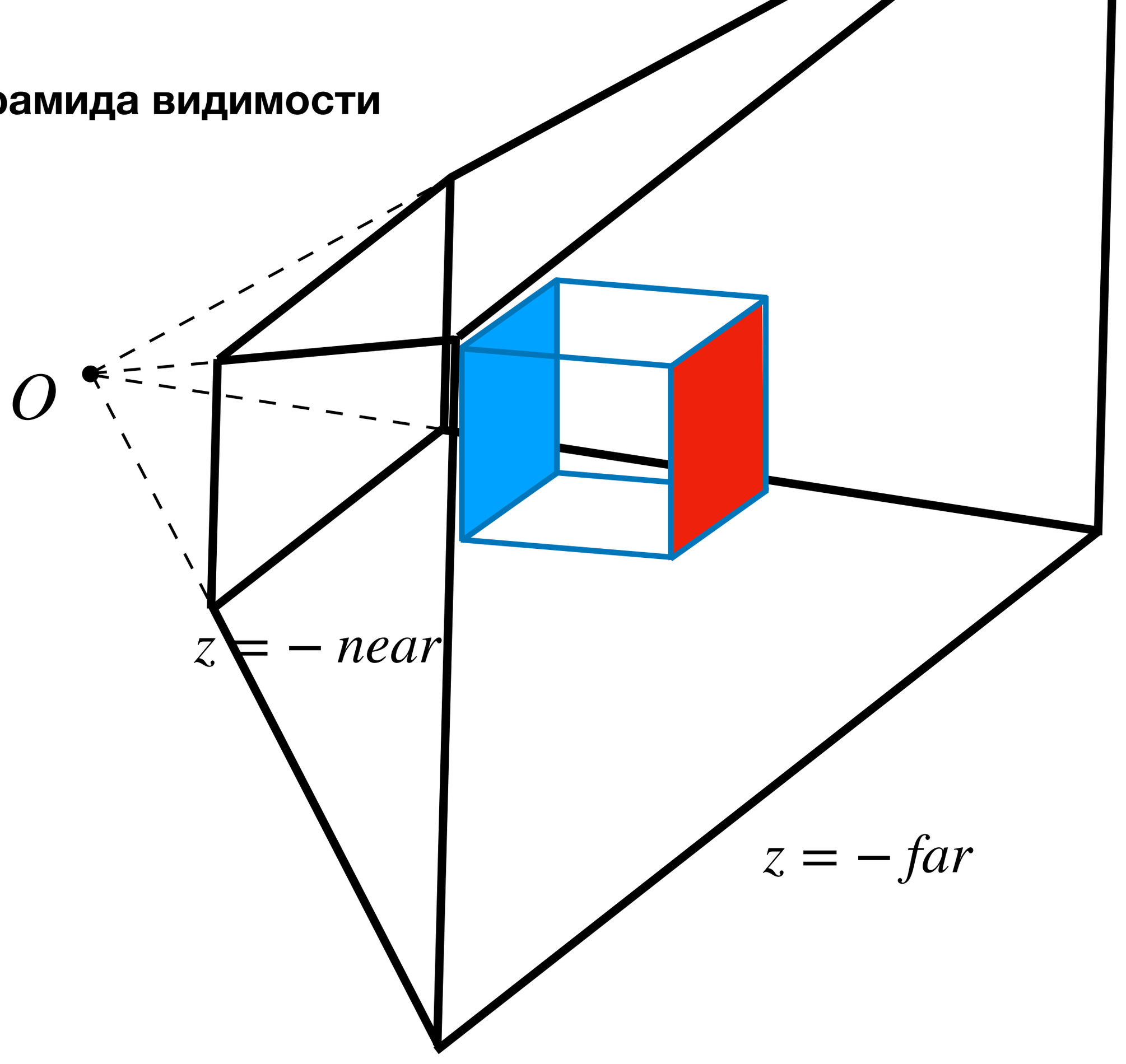
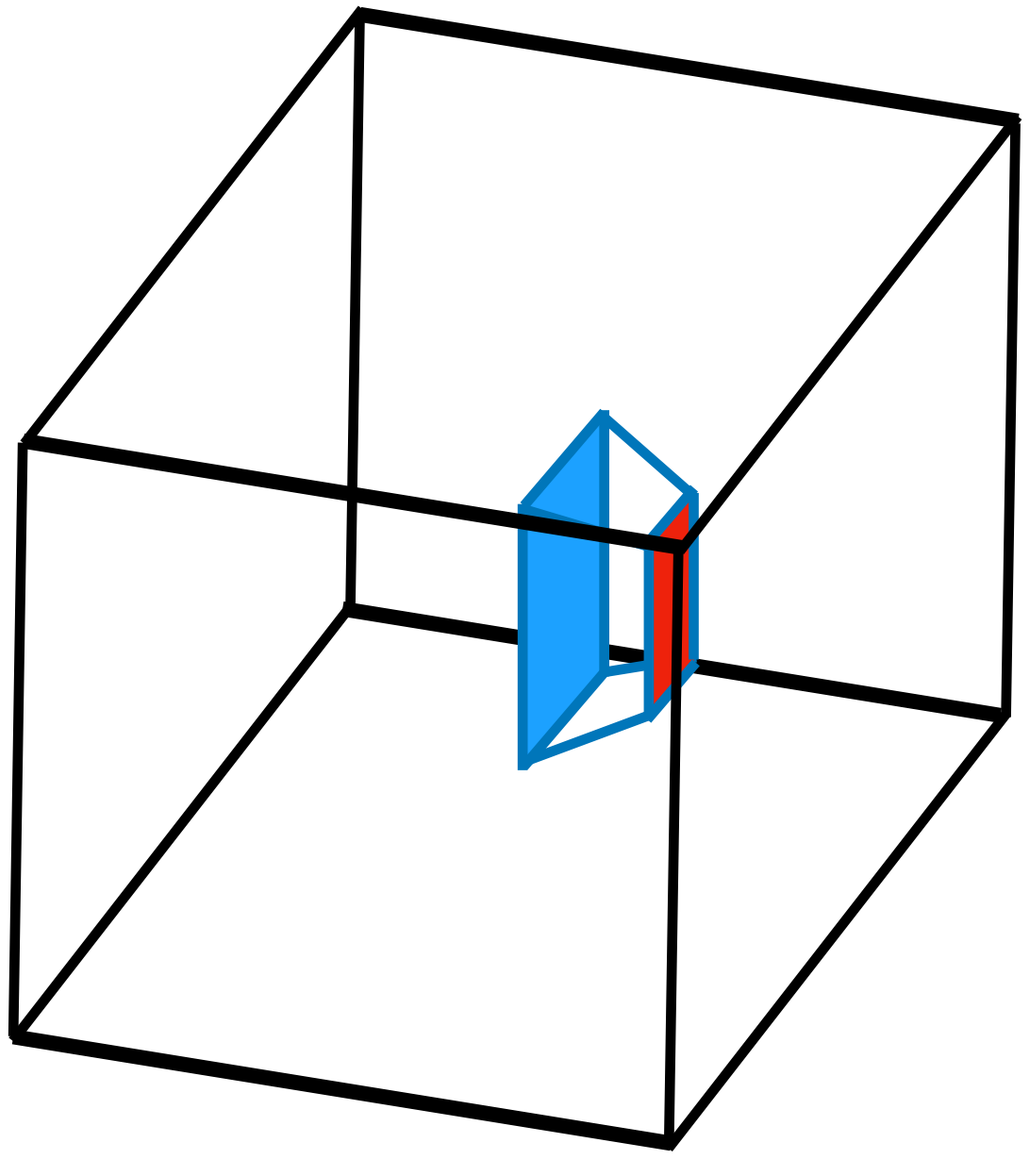


Пирамида видимости



Пространство отсечения



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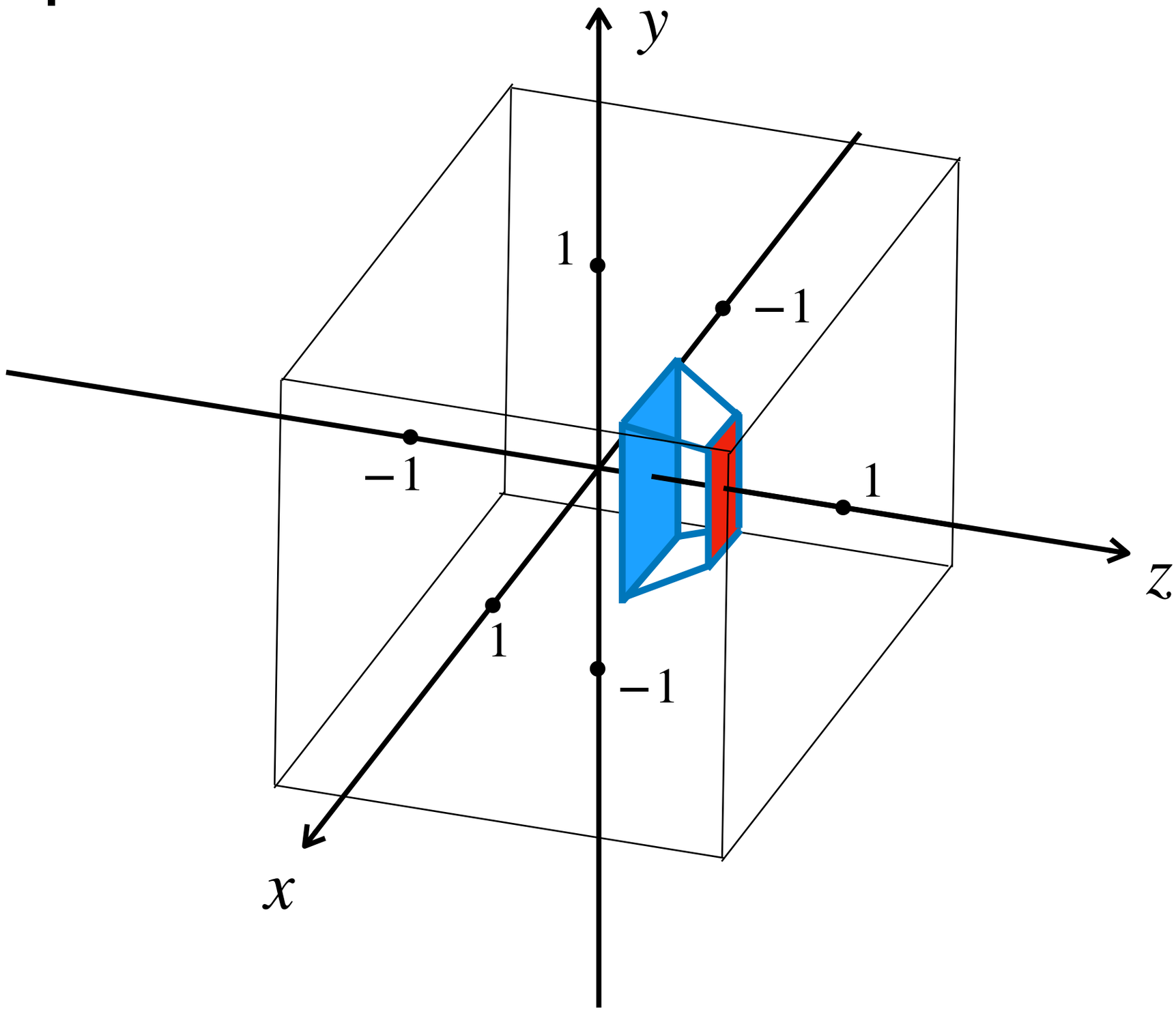

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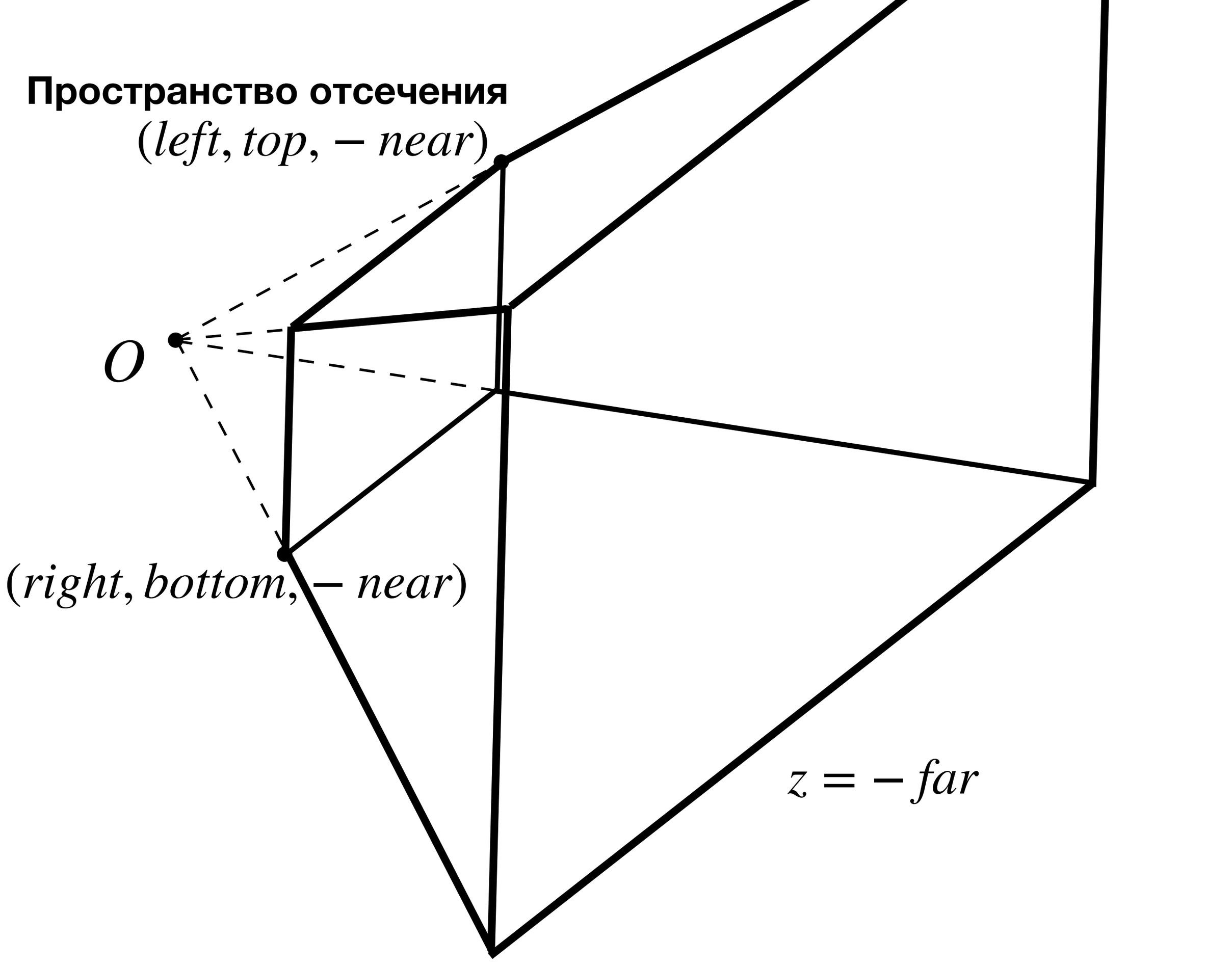

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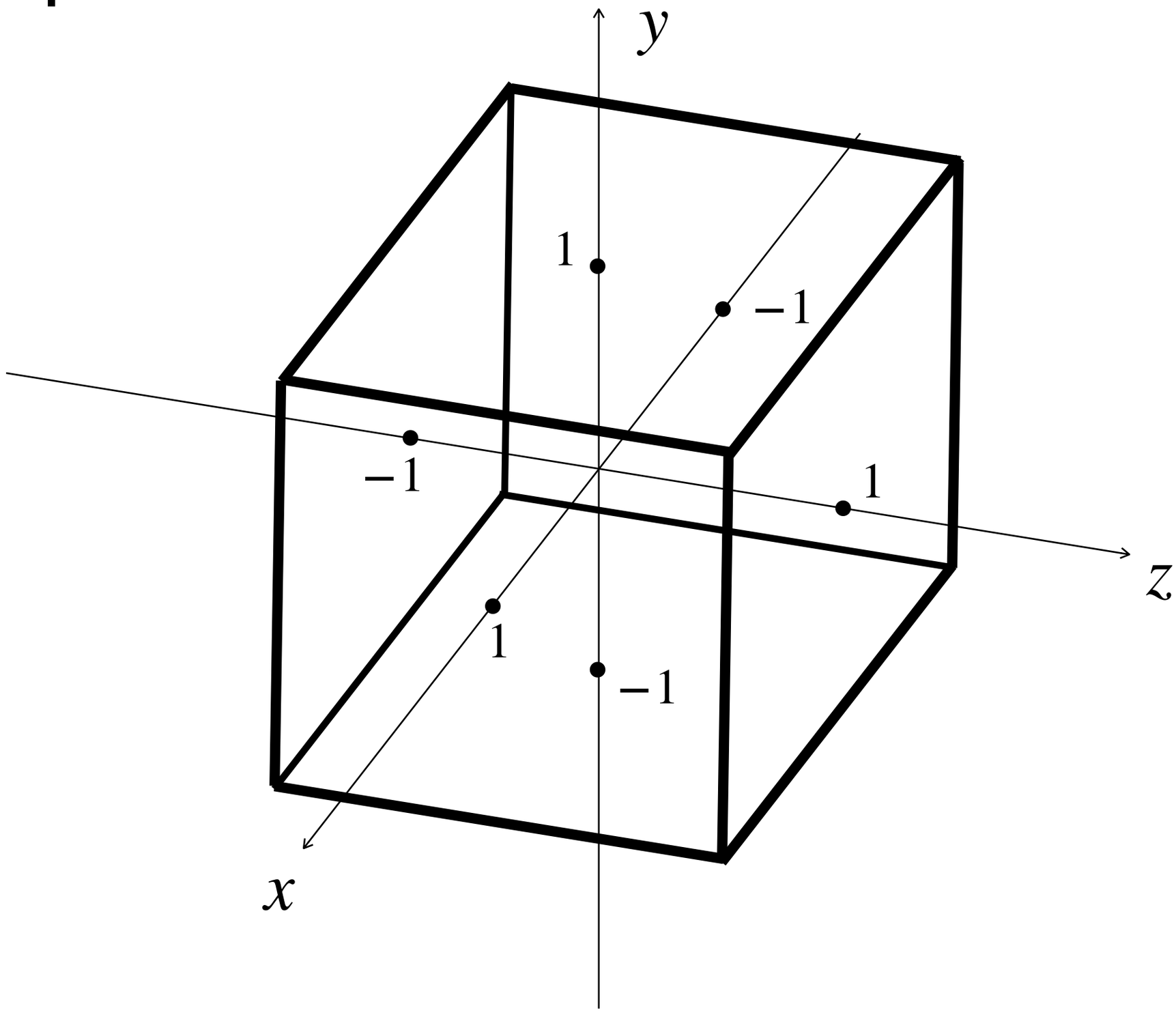

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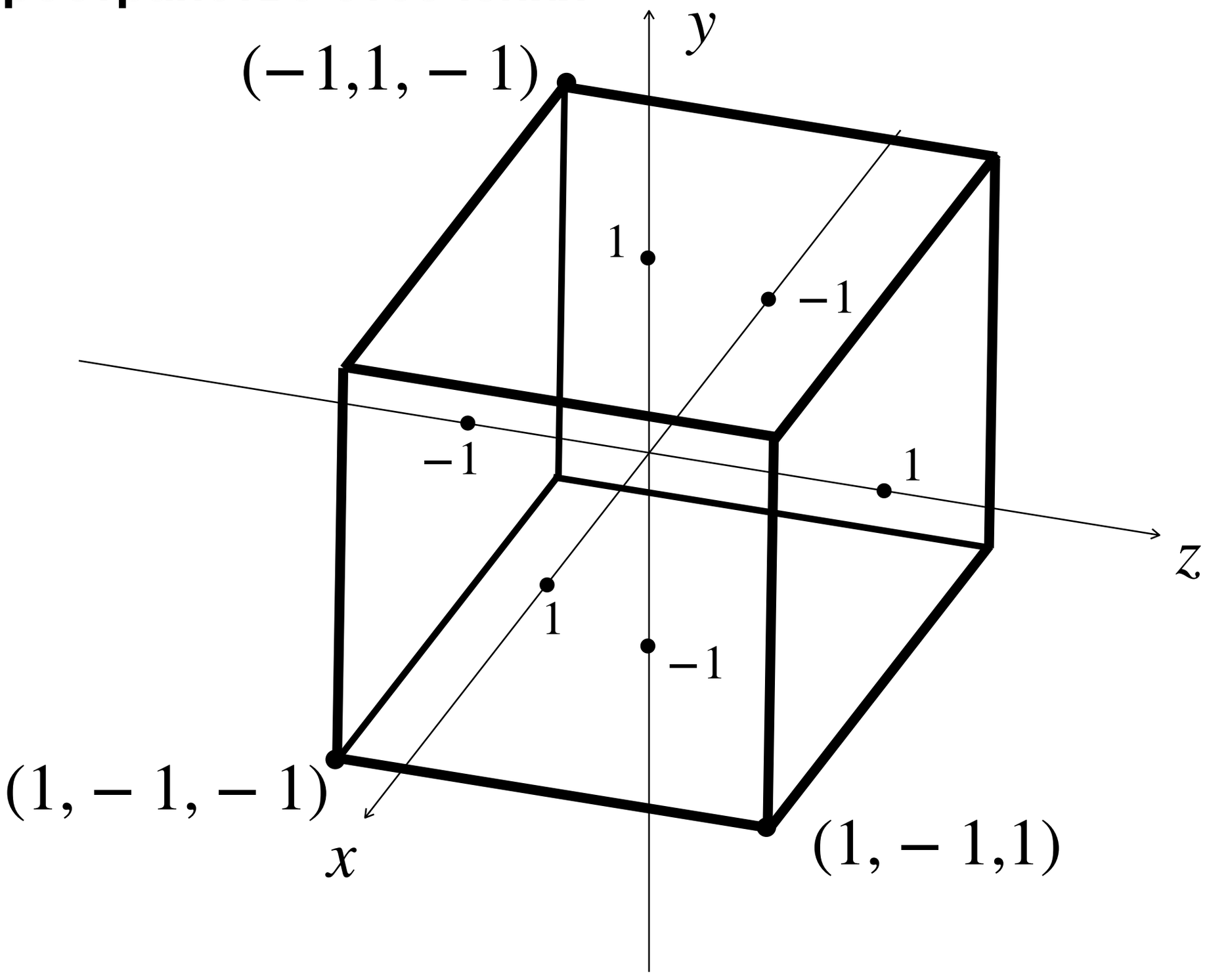
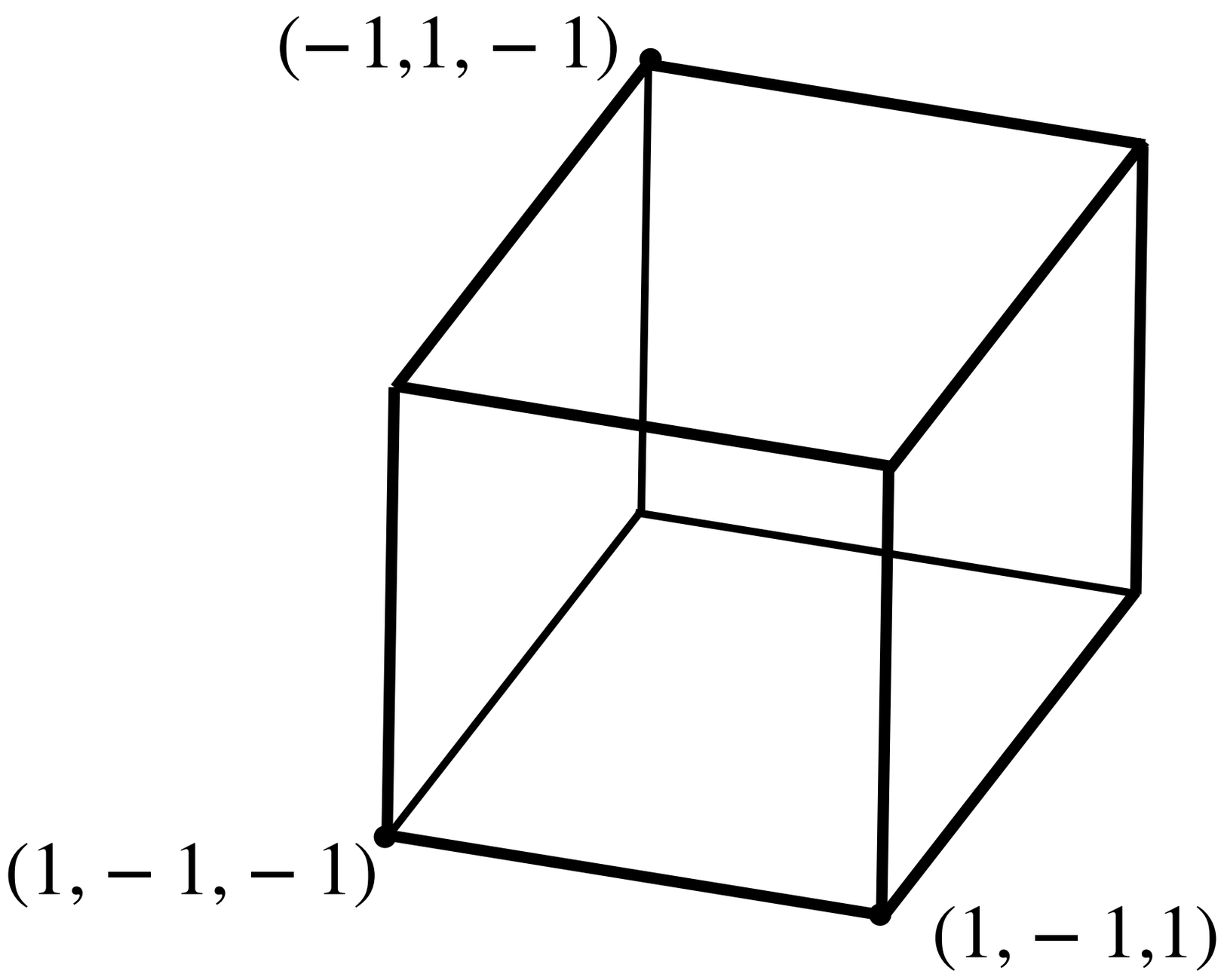
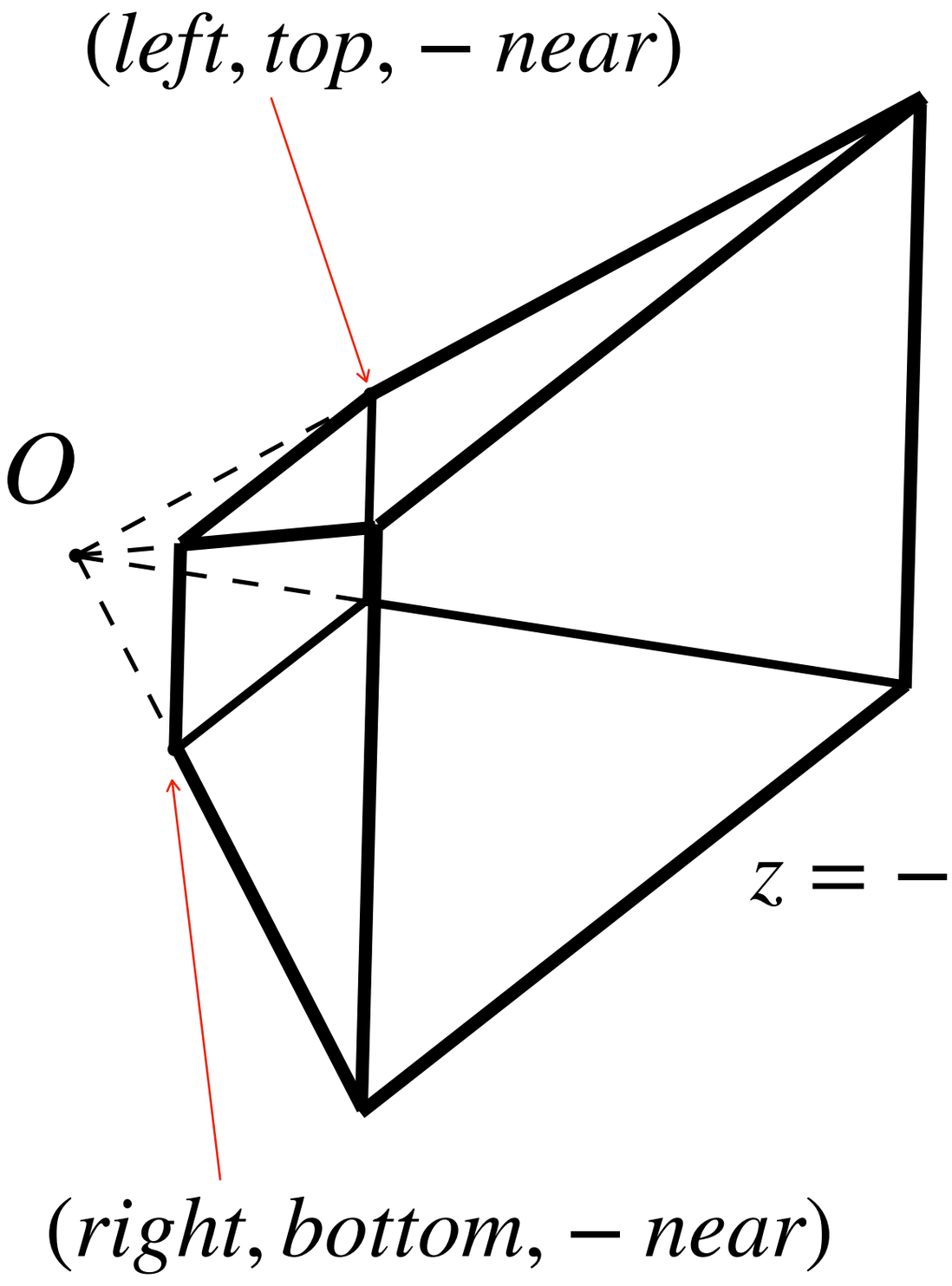
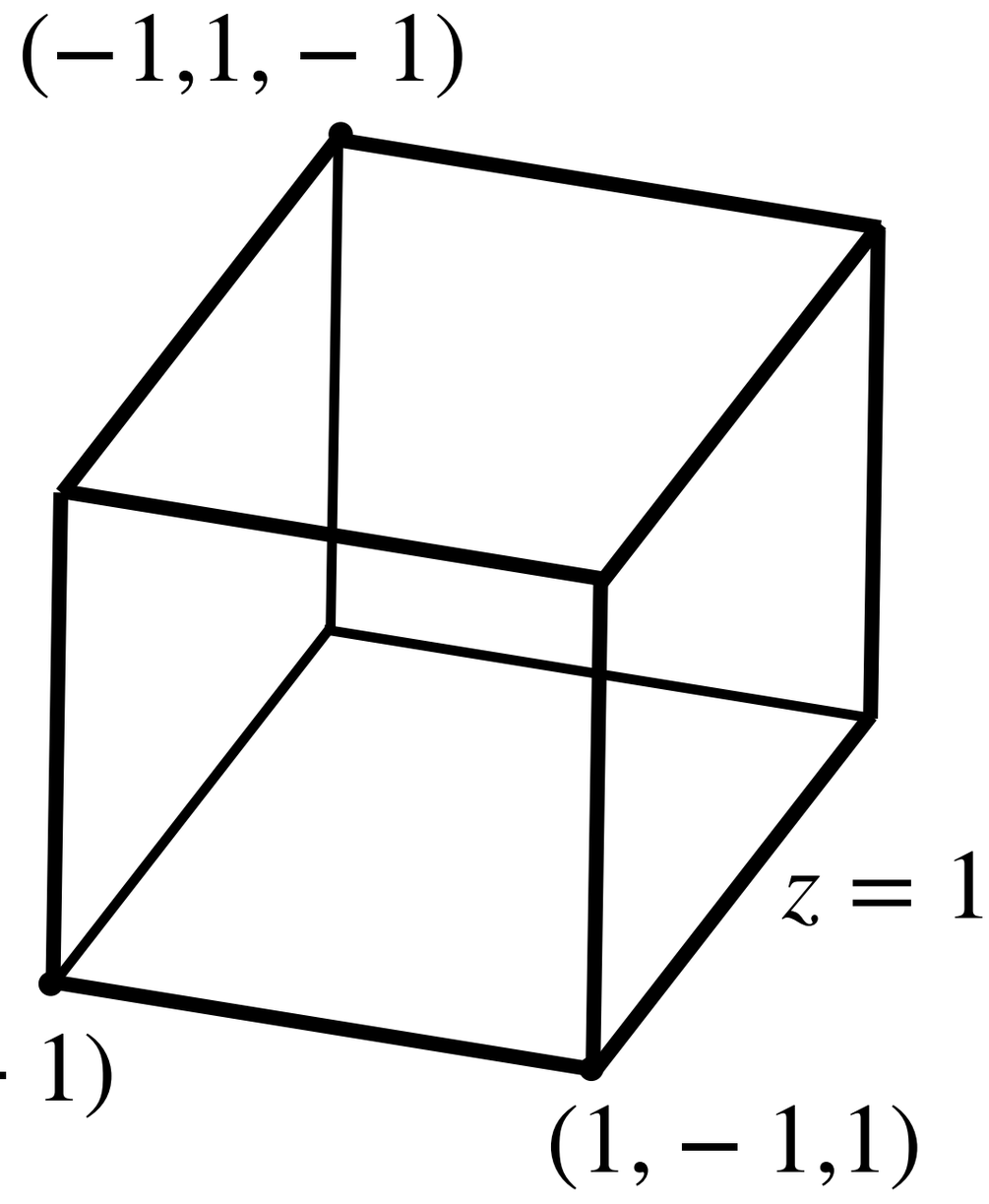


Пространство отсечения



Переход в пространство отсечения

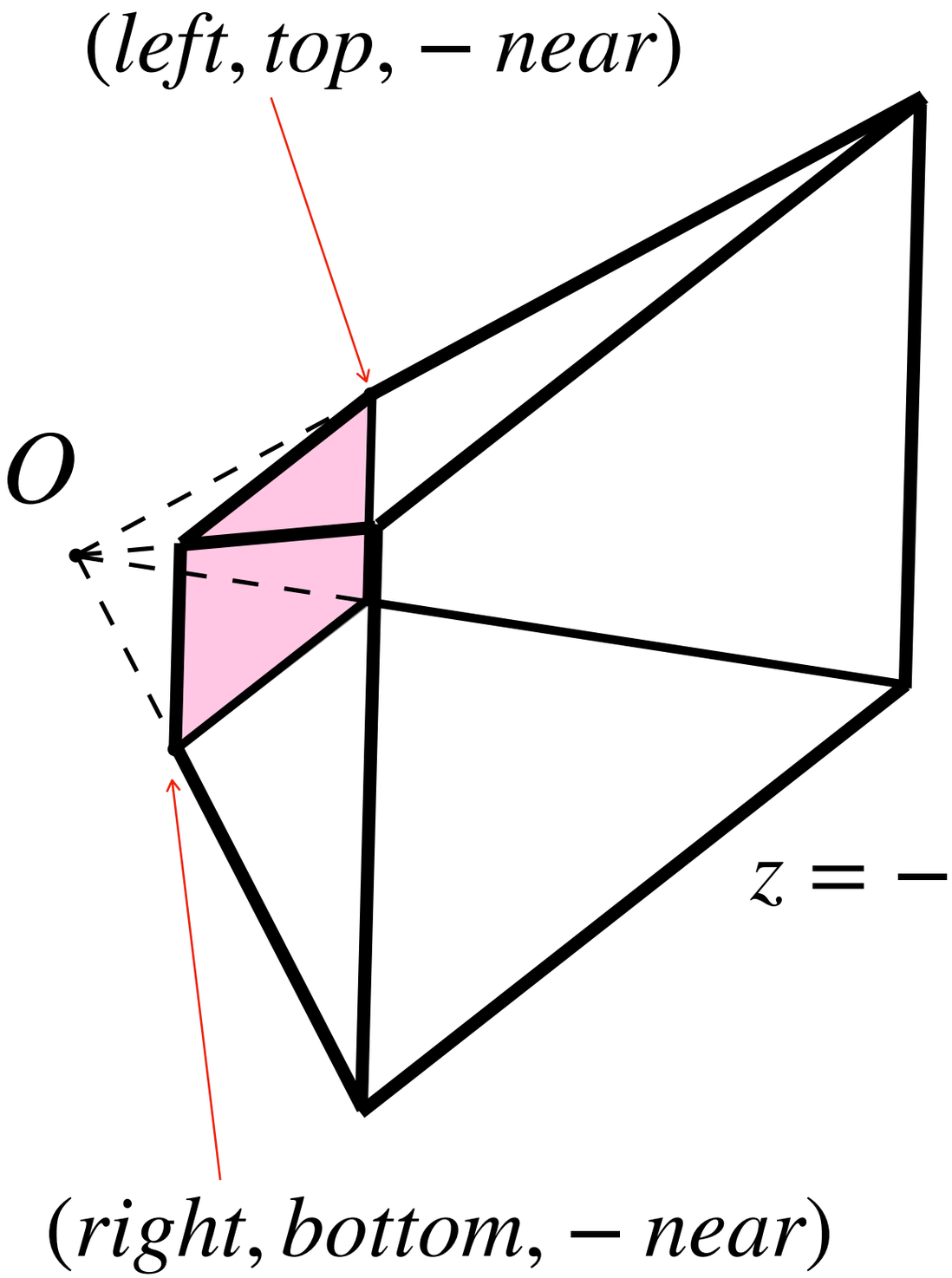


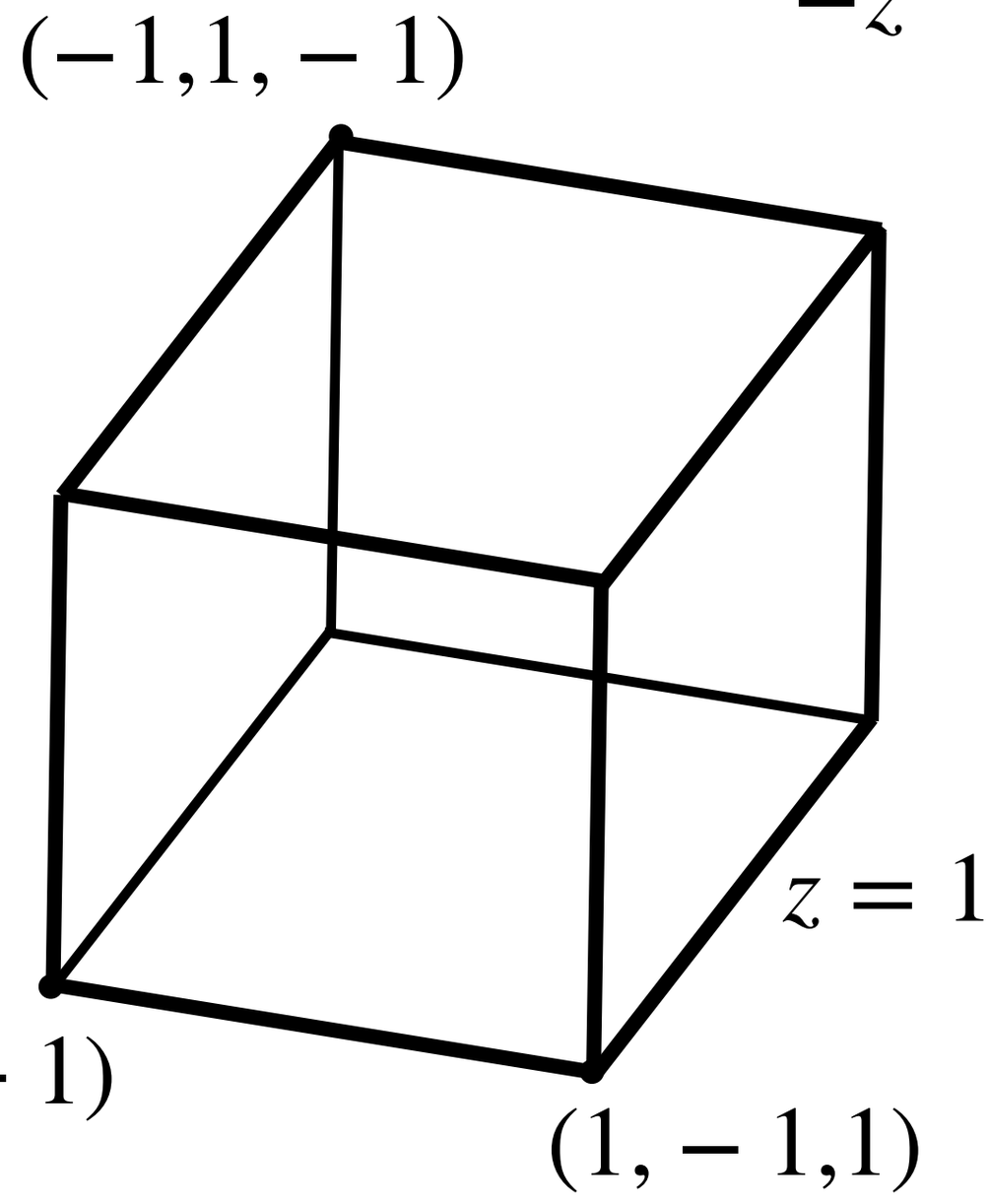


Переход в пространство отсечения

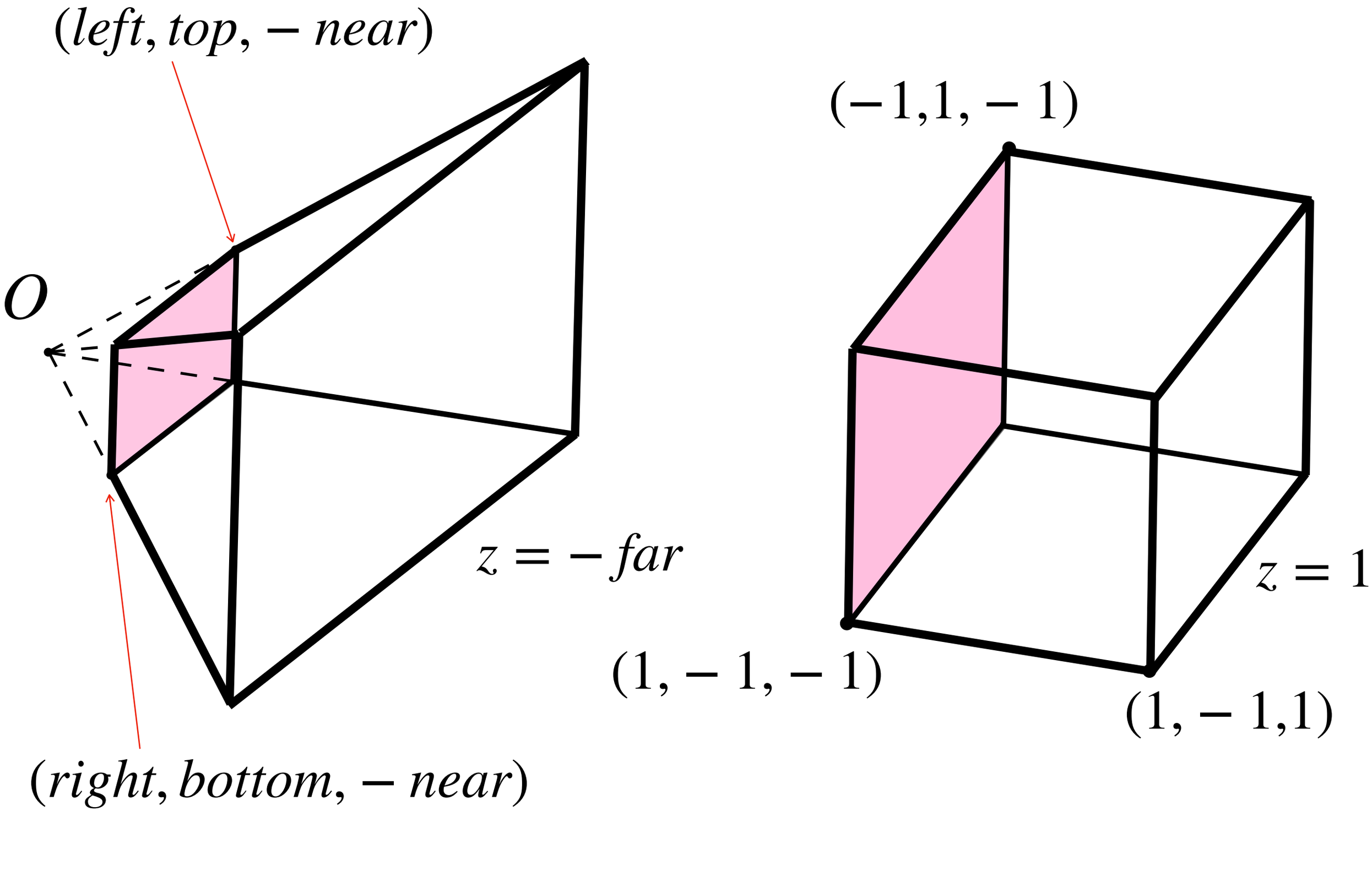
$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$

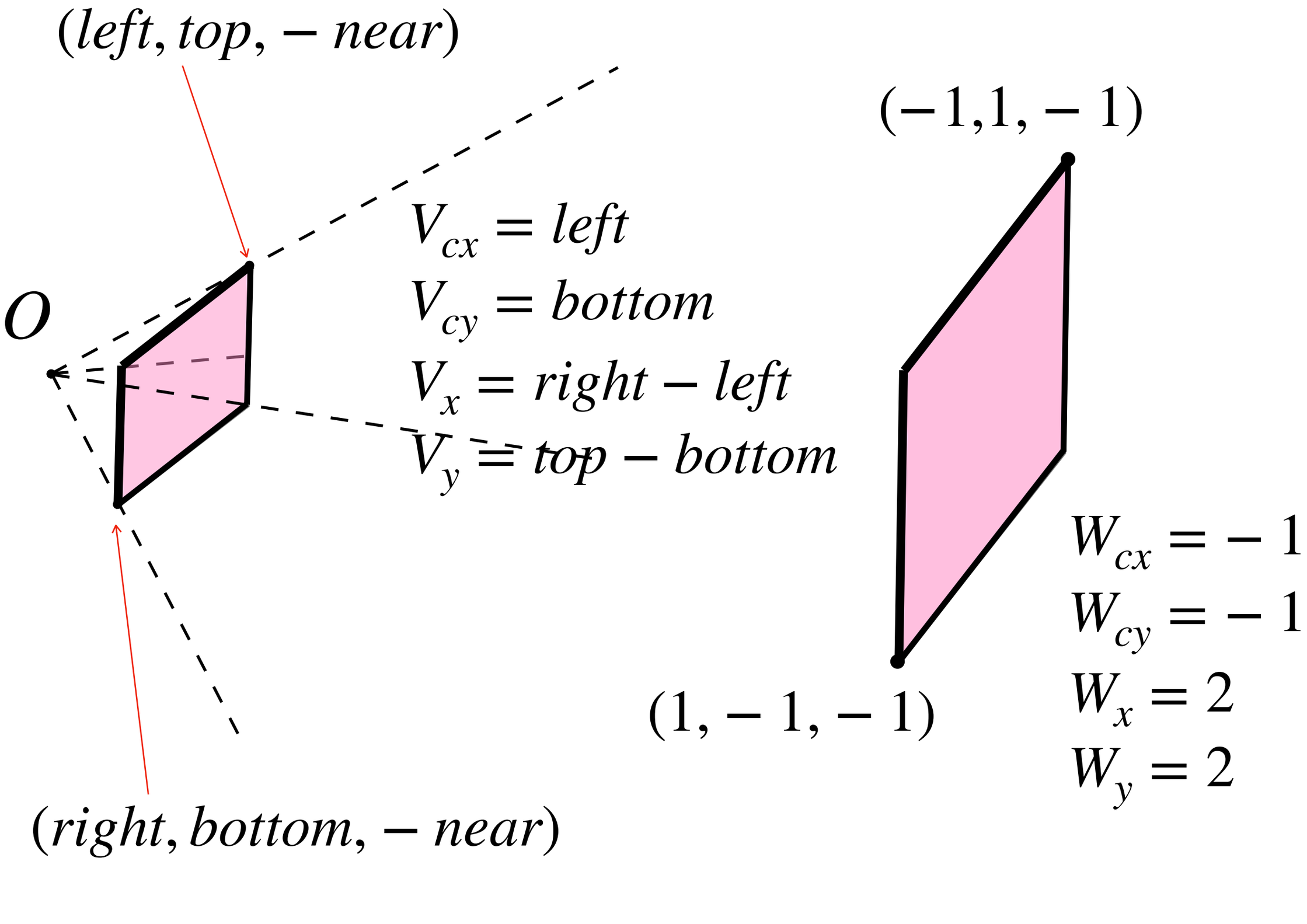




Переход в пространство отсечения

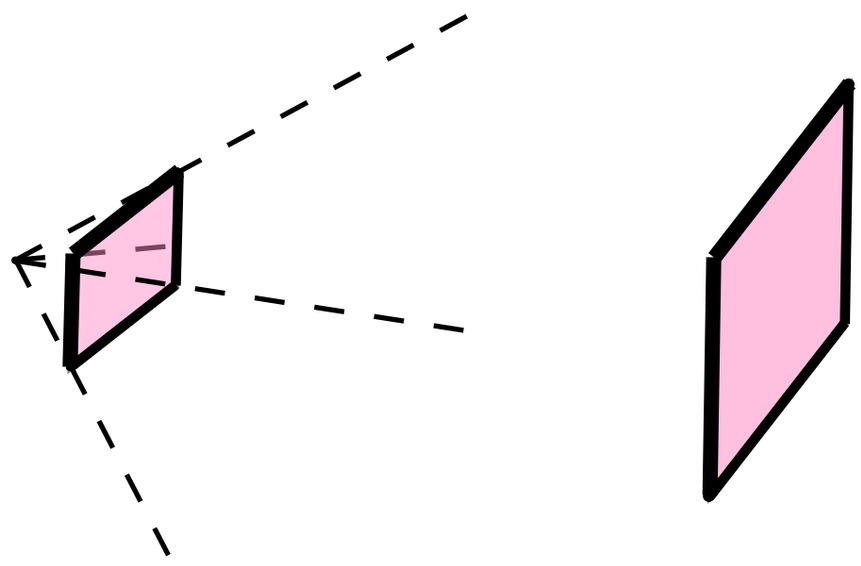


Переход в пространство отсечения



Переход в пространство отсечения

$$V_{cx} = left$$
$$V_{cy} = bottom$$
$$V_x = right - left$$
$$V_y = top - bottom$$



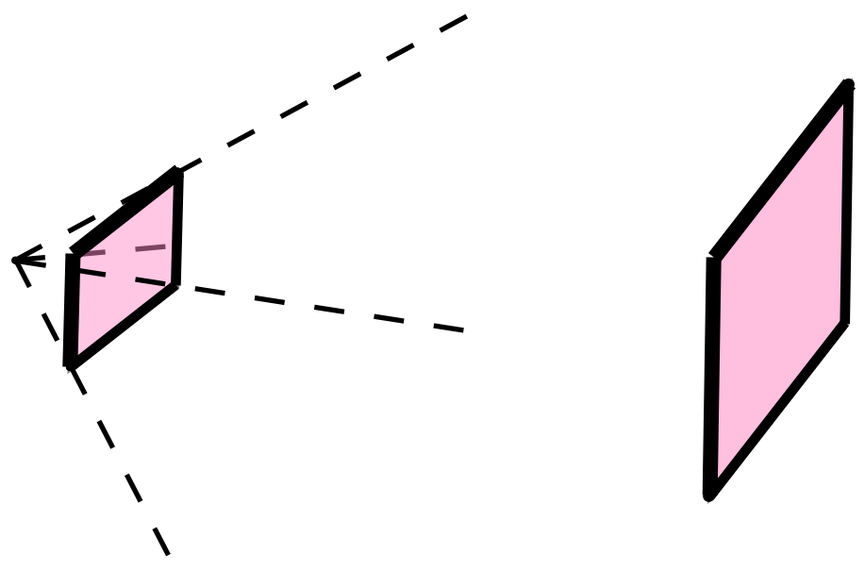
$$W_{cx} = -1$$
$$W_{cy} = -1$$
$$W_x = 2$$
$$W_y = 2$$

$$x'' = \frac{x' - left}{right - left} \cdot 2 - 1$$

$$y'' = \frac{y' - bottom}{top - bottom} \cdot 2 - 1$$

Переход в пространство отсечения

$$V_{cx} = left$$
$$V_{cy} = bottom$$
$$V_x = right - left$$
$$V_y = top - bottom$$



$$W_{cx} = -1$$
$$W_{cy} = -1$$
$$W_x = 2$$
$$W_y = 2$$

$$x'' = \frac{x' - left}{right - left} \cdot 2 - 1$$

$$y'' = \frac{y' - bottom}{top - bottom} \cdot 2 - 1$$

$$x' = near\frac{x}{-z}$$

$$y' = near\frac{y}{-z}$$

Переход в пространство отсечения

$$x'' = \frac{near\frac{x}{-z} - left}{right - left} \cdot 2 - 1$$

$$x'' = \frac{2 \cdot near \cdot x + 2 \cdot z \cdot left + z \cdot right - z \cdot left}{-z(right - left)}$$

$$x'' = \frac{x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}}{-z}$$

Переход в пространство отсечения

$$y'' = \frac{near\frac{y}{-z} - bottom}{top - bottom} \cdot 2 - 1$$

$$y'' = \frac{2 \cdot near \cdot y + 2 \cdot z \cdot bottom + z \cdot top - z \cdot bottom}{-z(top - bottom)}$$

$$y'' = \frac{y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}}{-z}$$

Матрица перспективного преобразования

$$x'' = \frac{x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}}{-z}$$

$$y'' = \frac{y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}}{-z}$$

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Матрица перспективного преобразования

$$x'' = \frac{x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}}{-z}$$

$$\alpha'' = -z$$

$$y'' = \frac{y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}}{-z}$$

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Матрица перспективного преобразования

$$\chi'' = x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}$$

$$\alpha'' = -z$$

$$\gamma'' = y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}$$

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Матрица перспективного преобразования

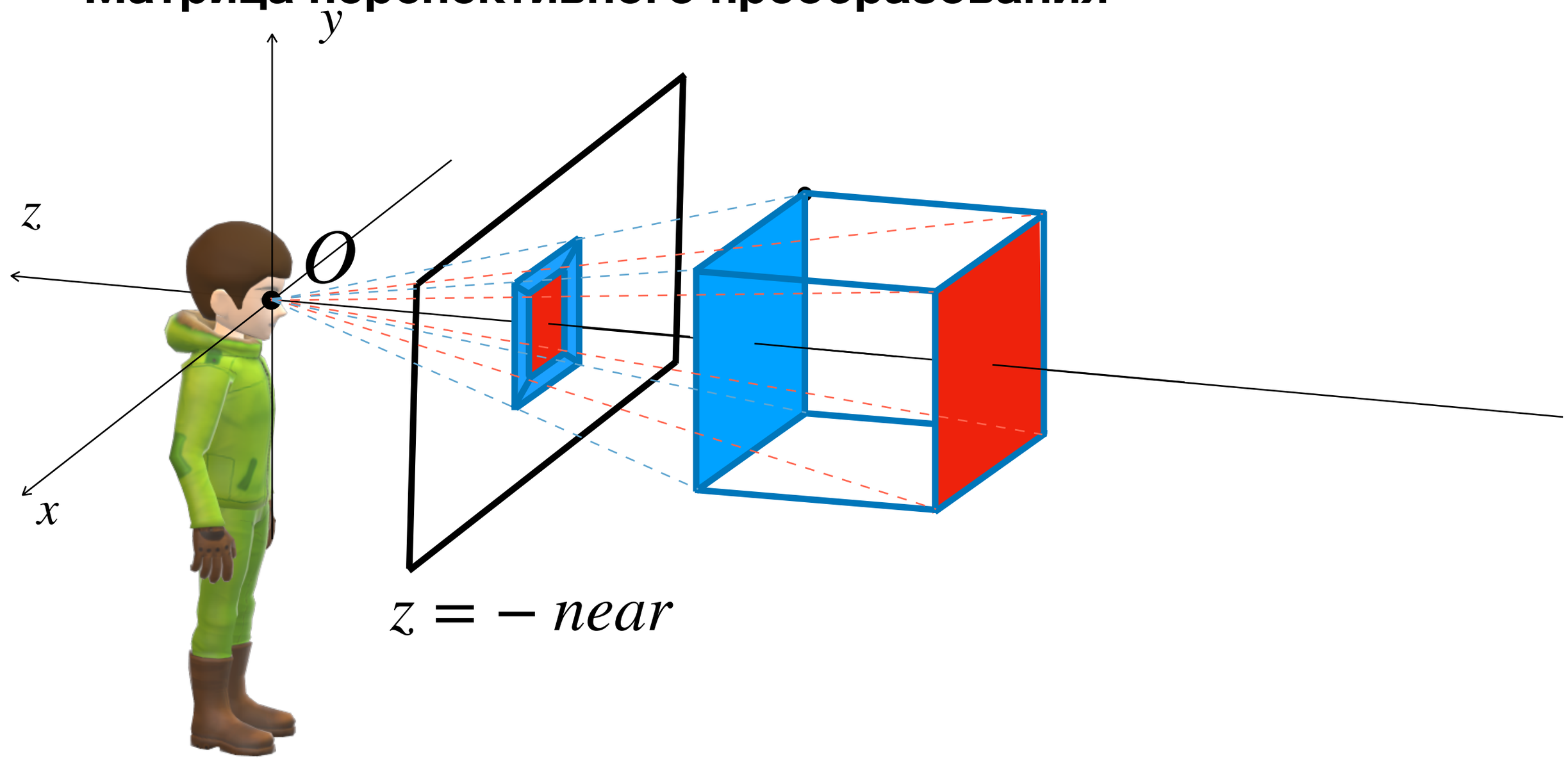
$$\chi'' = x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}$$

$$\alpha'' = -z$$

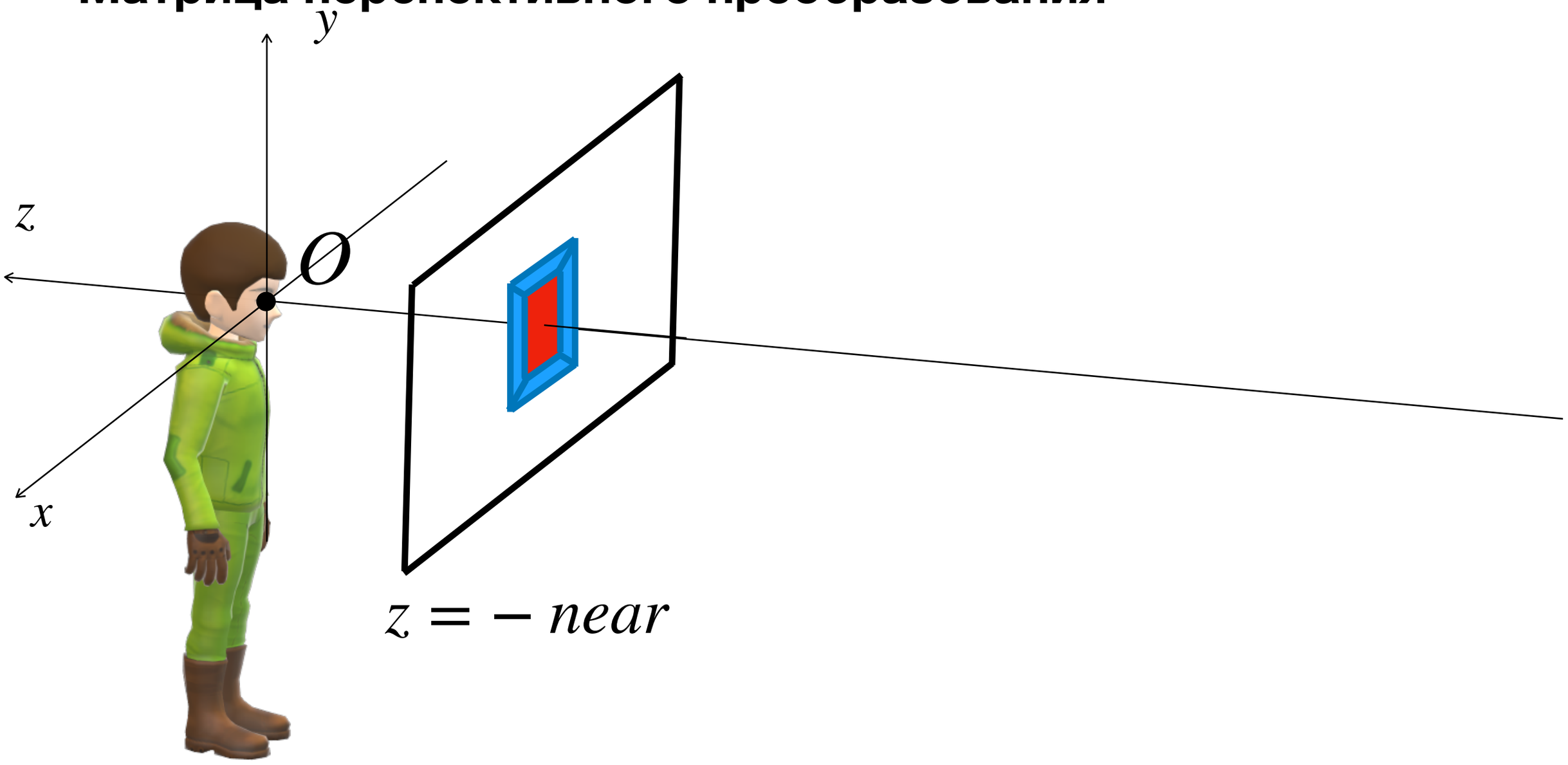
$$\gamma'' = y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}$$

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

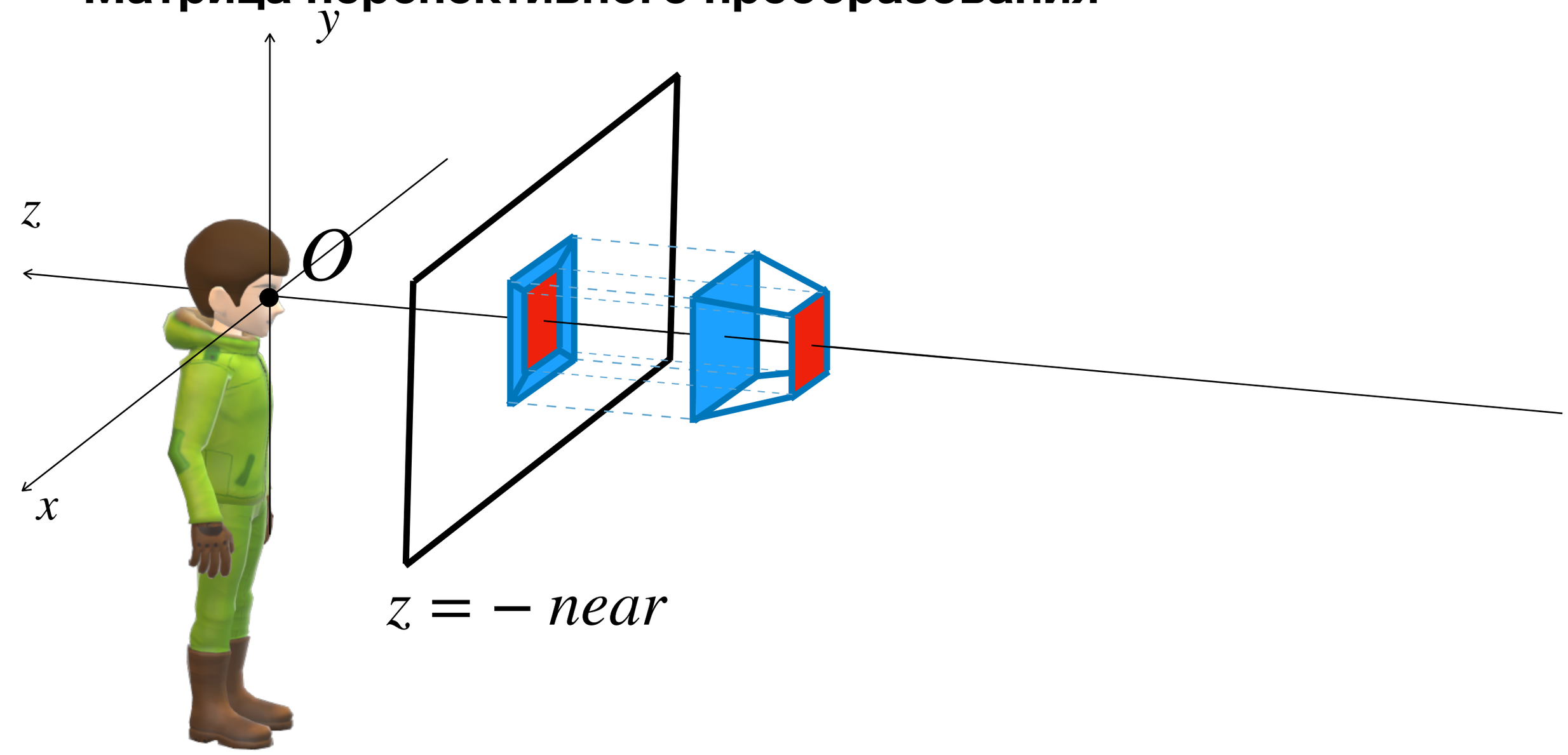
Матрица перспективного преобразования



Матрица перспективного преобразования



Матрица перспективного преобразования



Матрица перспективного преобразования

$$\chi'' = x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}$$

$$\alpha'' = -z$$

$$\gamma'' = y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}$$

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

Матрица перспективного преобразования

$$\chi'' = x\frac{2 \cdot near}{right - left} + z\frac{right + left}{right - left}$$

$$\alpha'' = -z$$

$$\gamma'' = y\frac{2 \cdot near}{top - bottom} + z\frac{top + bottom}{top - bottom}$$

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ 0 & 0 & a_{33} & a_{34} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

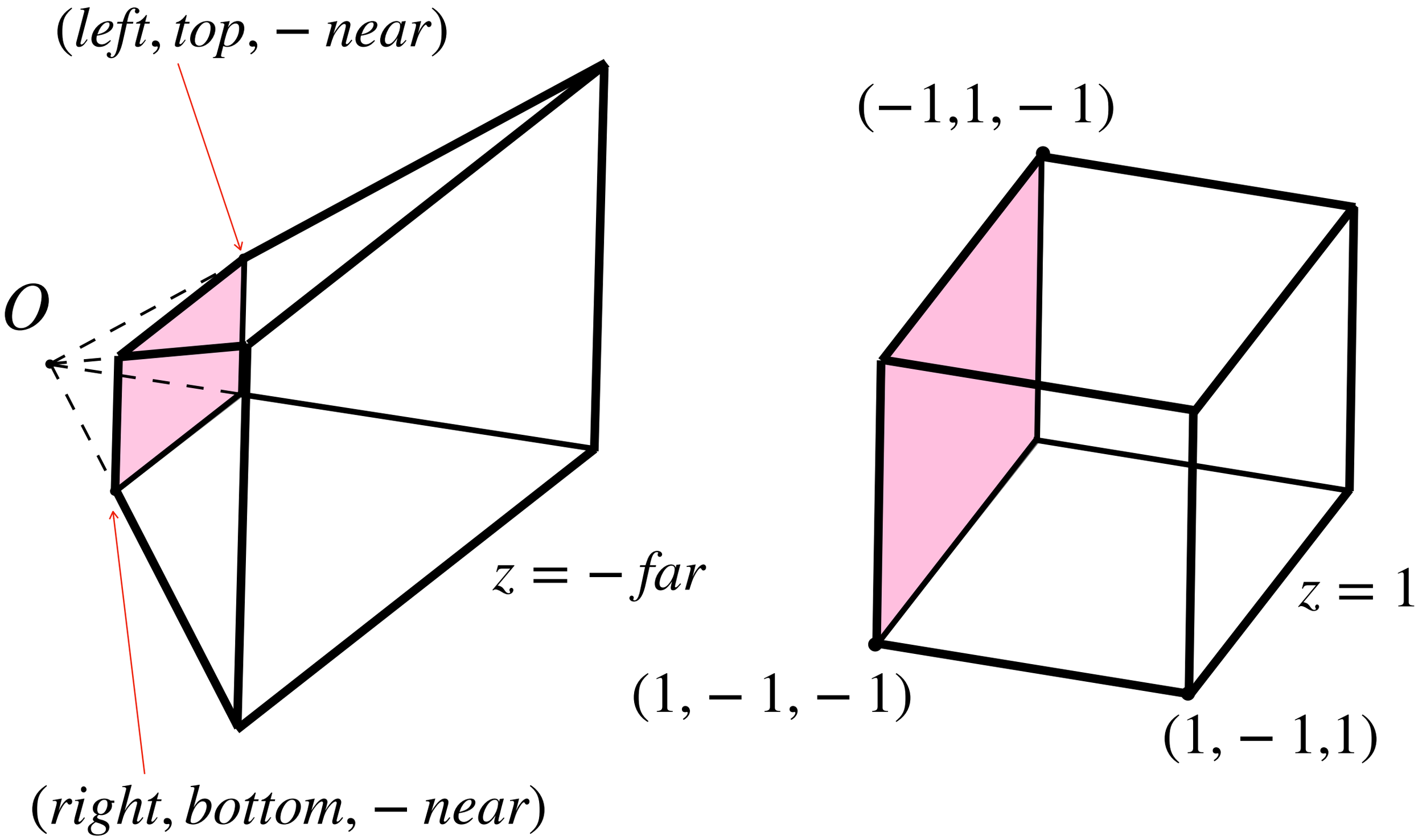
Матрица перспективного преобразования

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ 0 & 0 & a_{33} & a_{34} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$\zeta'' = a_{33} z + a_{34} \qquad z'' = -a_{33} - \frac{a_{34}}{z}$$

$$\alpha'' = -z$$

Матрица перспективного преобразования



Матрица перспективного преобразования

$$\zeta'' = a_{33}z + a_{34} \qquad z'' = -a_{33} - \frac{a_{34}}{z}$$
$$\alpha'' = -z$$

$$z = -near \quad \Rightarrow \quad z'' = -1$$
$$z = -far \quad \Rightarrow \quad z'' = 1$$

$$-a_{33} - \frac{a_{34}}{-near} = -1$$
$$-a_{33} - \frac{a_{34}}{-far} = 1$$

Матрица перспективного преобразования

$$-a_{33} - \frac{a_{34}}{-near} = -1$$

$$-a_{33} - \frac{a_{34}}{-far} = 1$$

$$\frac{a_{34}}{-near} - \frac{a_{34}}{-far} = 2$$

$$a_{34}\frac{far - near}{-far \cdot near} = 2$$

$$a_{34} = \frac{-2 \cdot far \cdot near}{far - near}$$

Матрица перспективного преобразования

$$-a_{33} - \frac{a_{34}}{-near} = -1$$

$$-a_{33} - \frac{a_{34}}{-far} = 1$$

$$\frac{a_{34}}{-near} - \frac{a_{34}}{-far} = 2$$

$$a_{34}\frac{far - near}{-far \cdot near} = 2$$

$$a_{34} = \frac{-2 \cdot far \cdot near}{far - near}$$

$$-a_{33} - \frac{\frac{-2 \cdot far \cdot near}{far - near}}{-far} = 1$$

$$-a_{33} - \frac{2 \cdot near}{far - near} = 1$$

$$a_{33} = -\frac{2 \cdot near}{far - near} - 1$$

$$a_{33} = -\frac{2 \cdot near + far - near}{far - near}$$

$$a_{33} = -\frac{far + near}{far - near}$$

Матрица перспективного преобразования

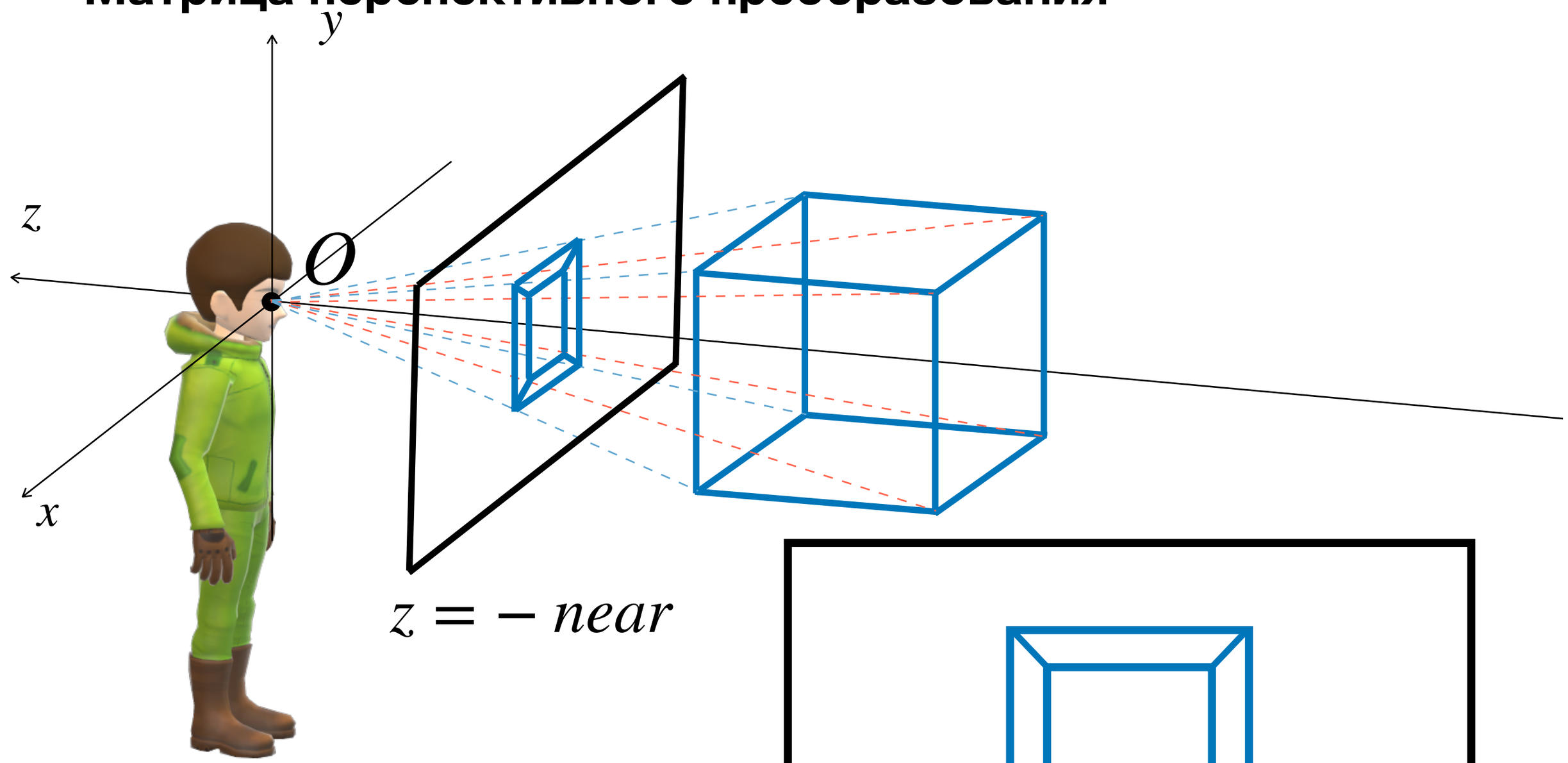
$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ 0 & 0 & -\frac{far + near}{far - near} & \frac{-2 \cdot far \cdot near}{far - near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

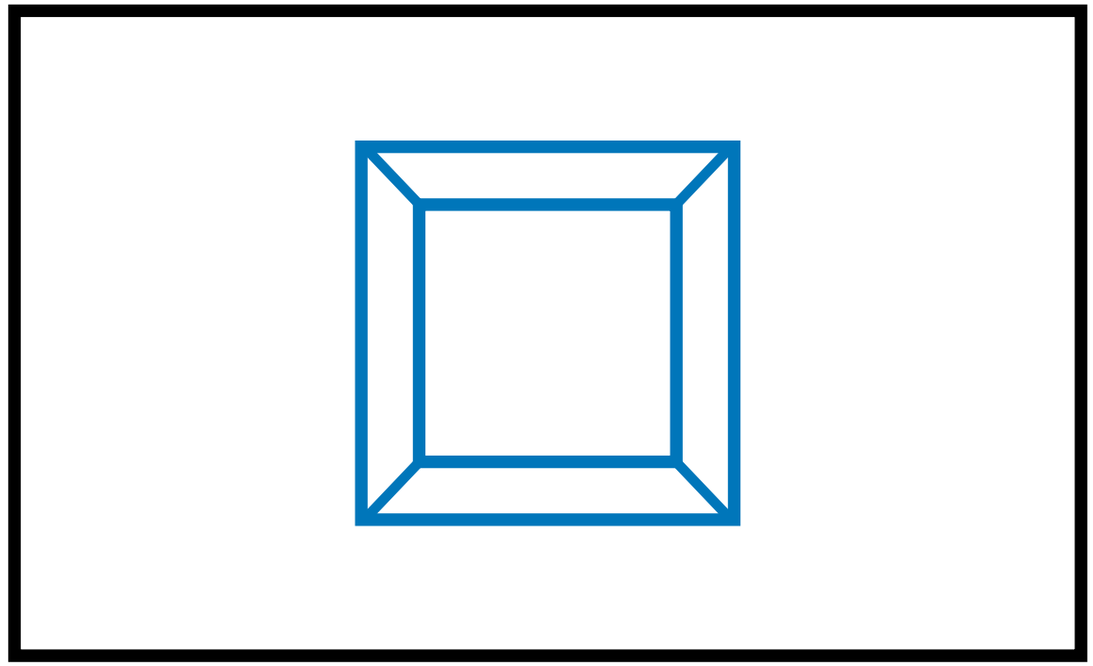
Матрица перспективного преобразования

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ 0 & 0 & -\frac{far + near}{far - near} & \frac{-2 \cdot far \cdot near}{far - near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

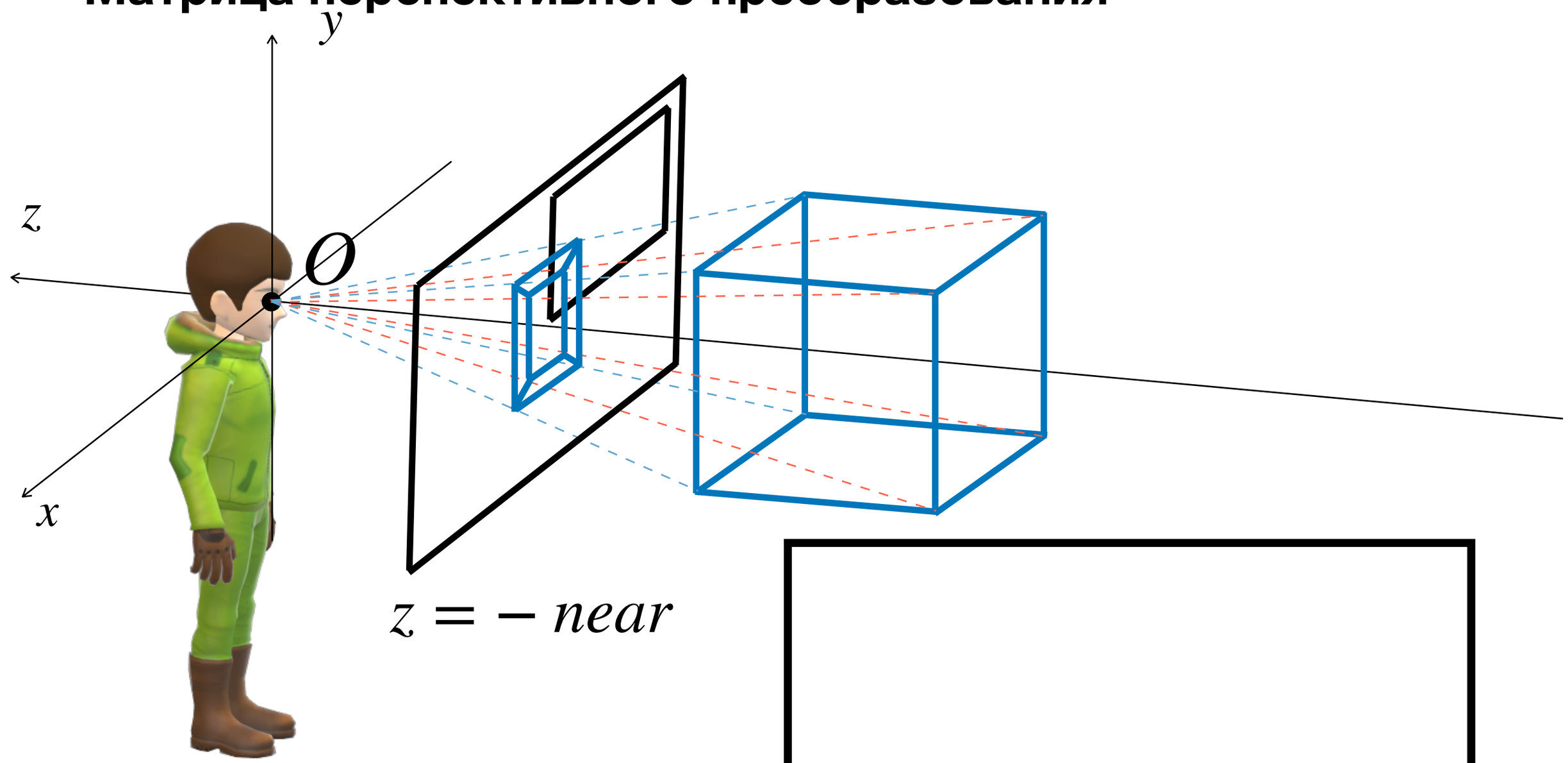
$$Frustum(left, right, bottom, top, near, far)$$

Матрица перспективного преобразования



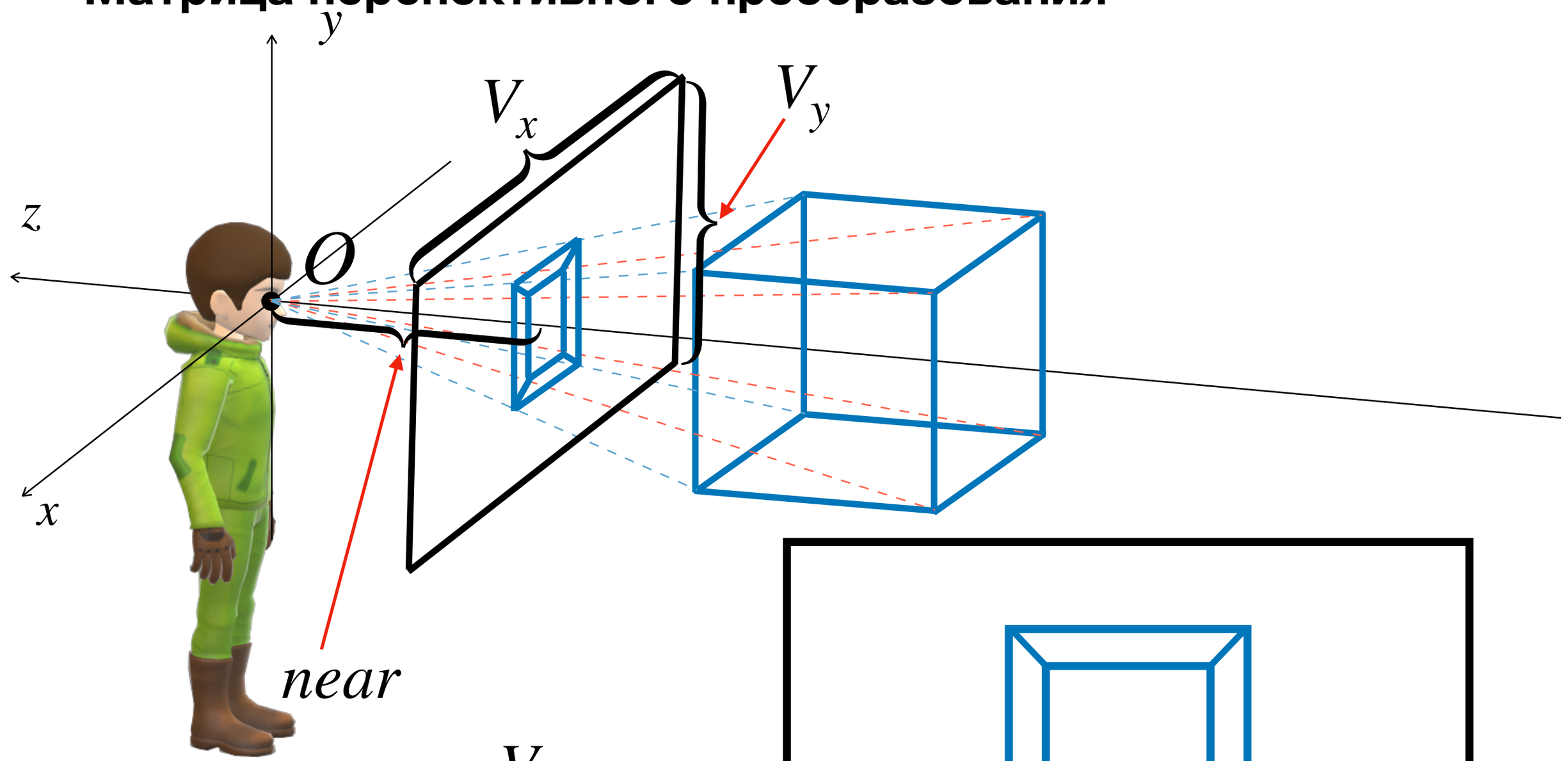


Матрица перспективного преобразования

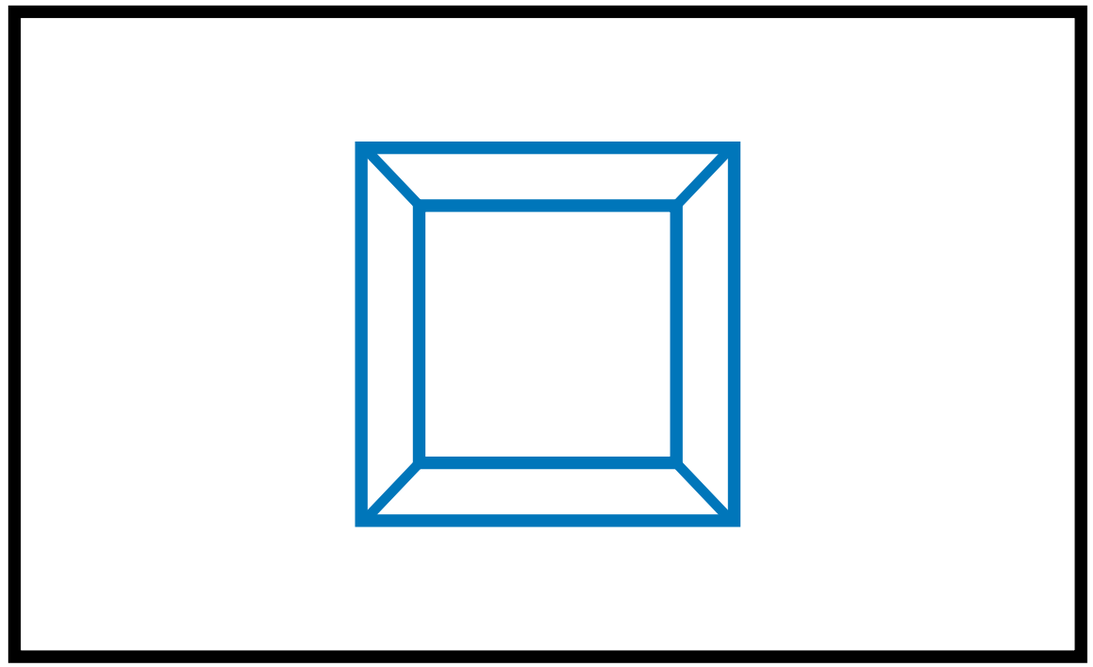


$z = -near$

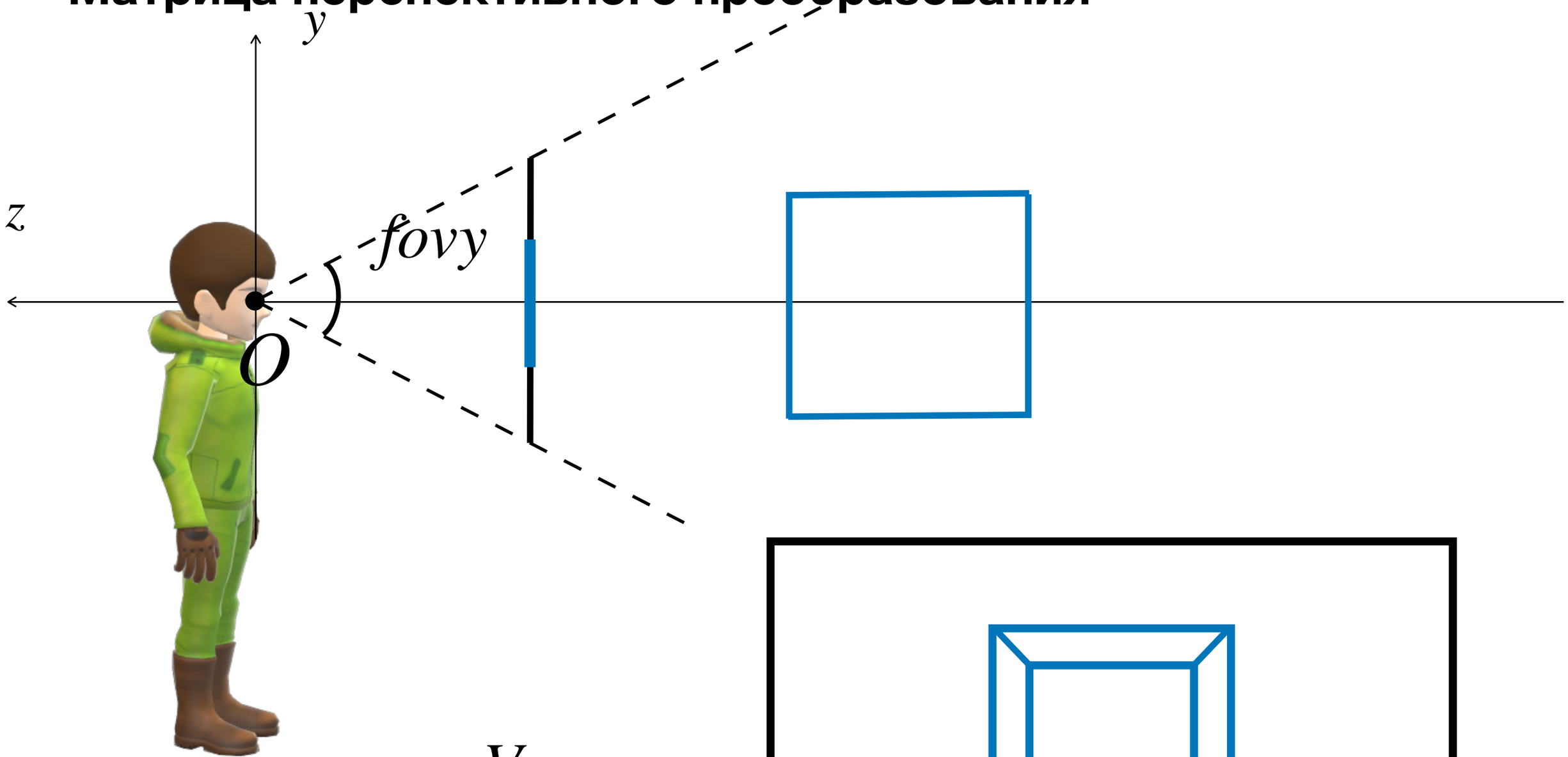
Матрица перспективного преобразования

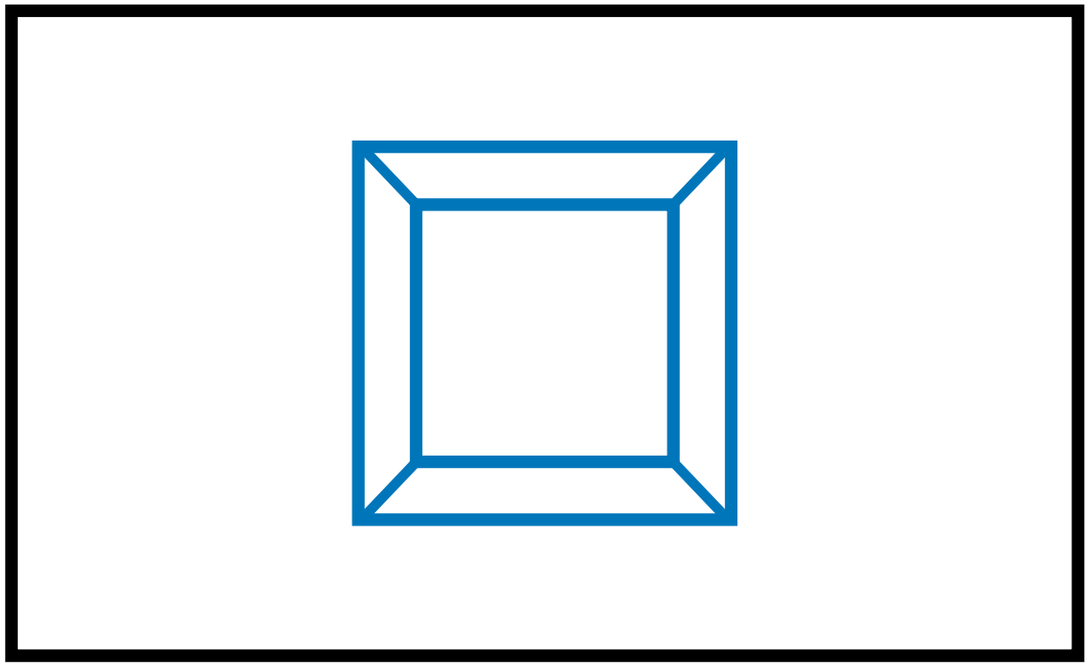


$$aspect = \frac{V_x}{V_y}$$



Матрица перспективного преобразования



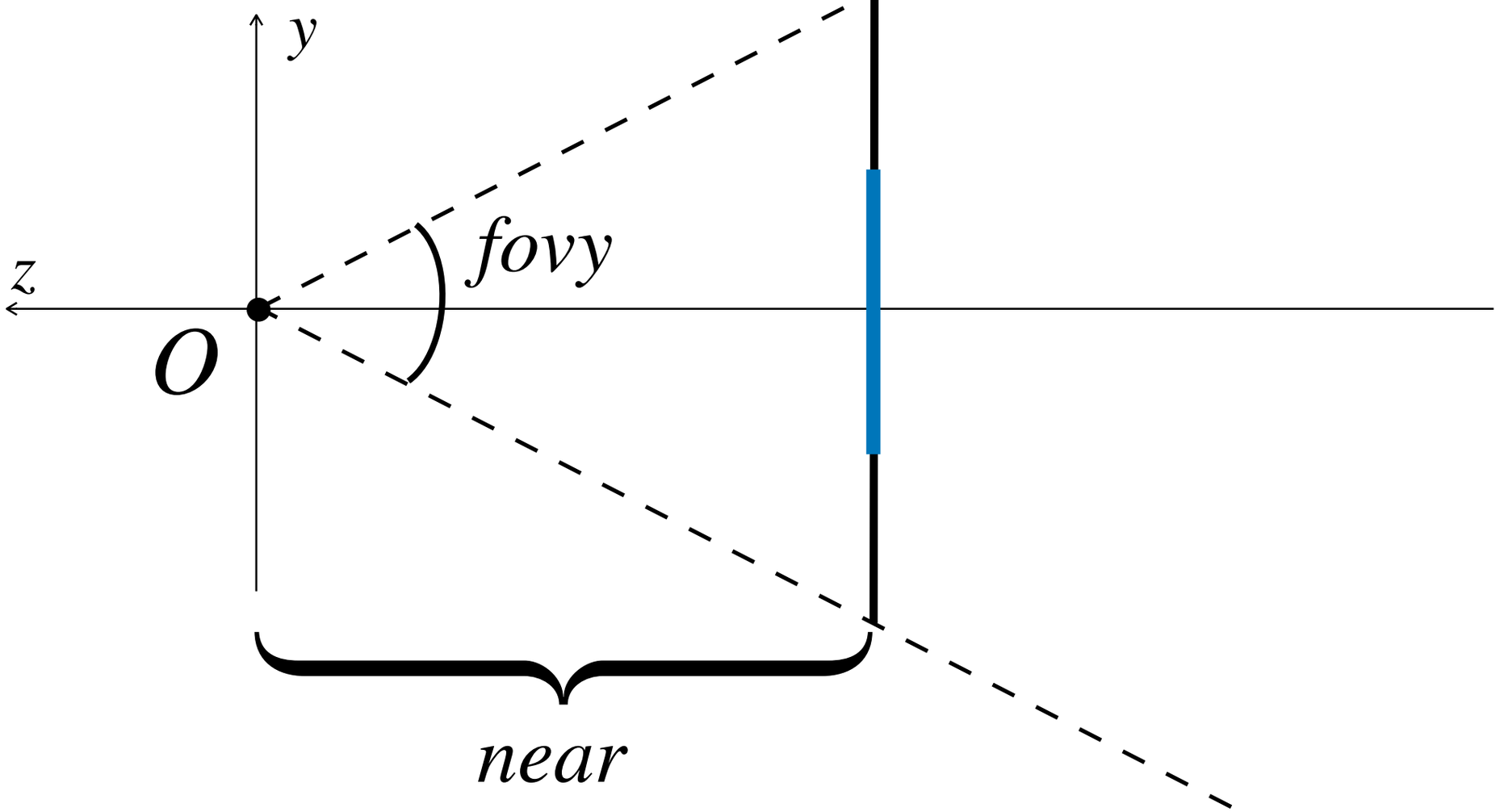


$$aspect = \frac{V_x}{V_y}$$

$near$

far

Матрица перспективного преобразования



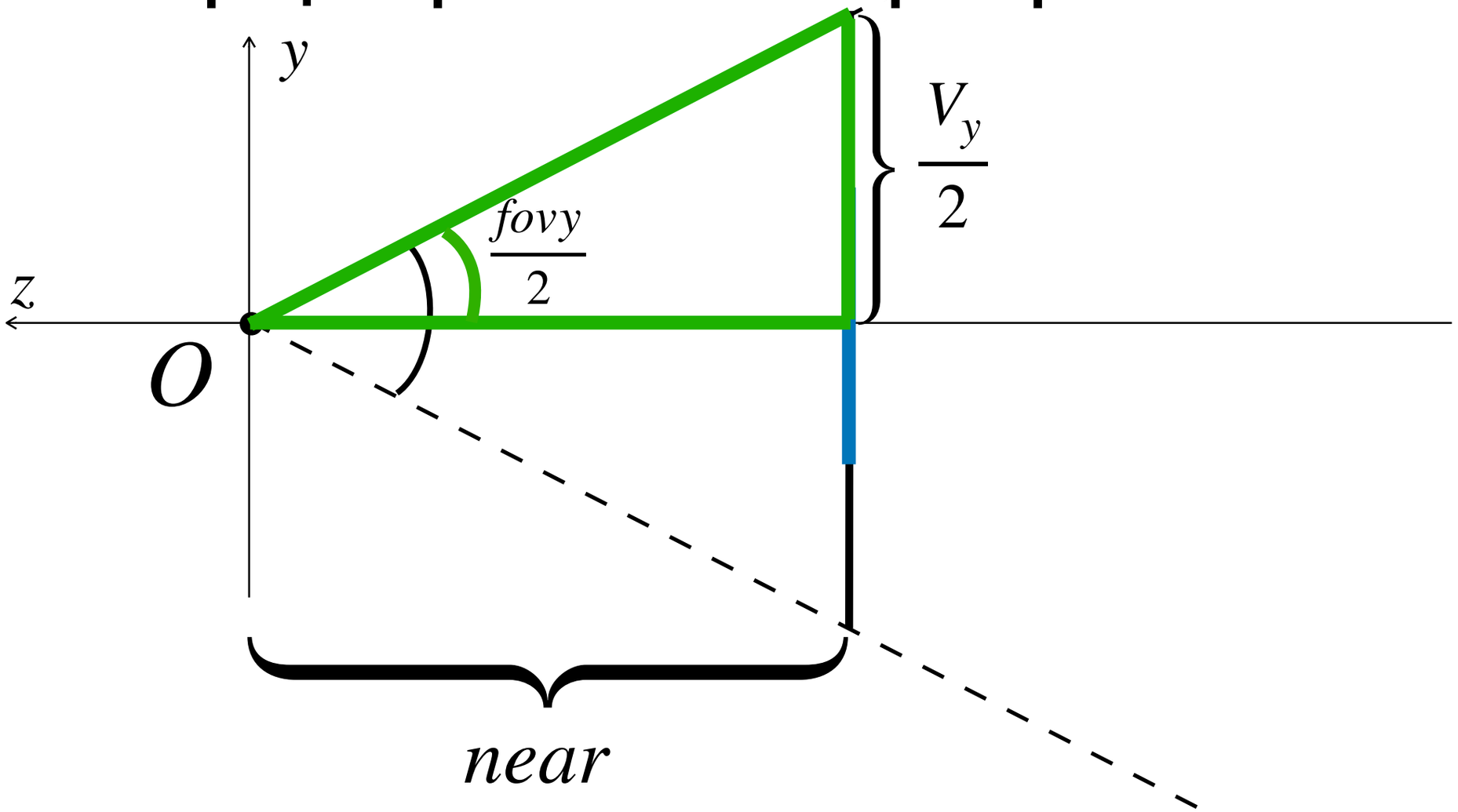
$$aspect = \frac{V_x}{V_y}$$

$fovy$

$near$

far

Матрица перспективного преобразования

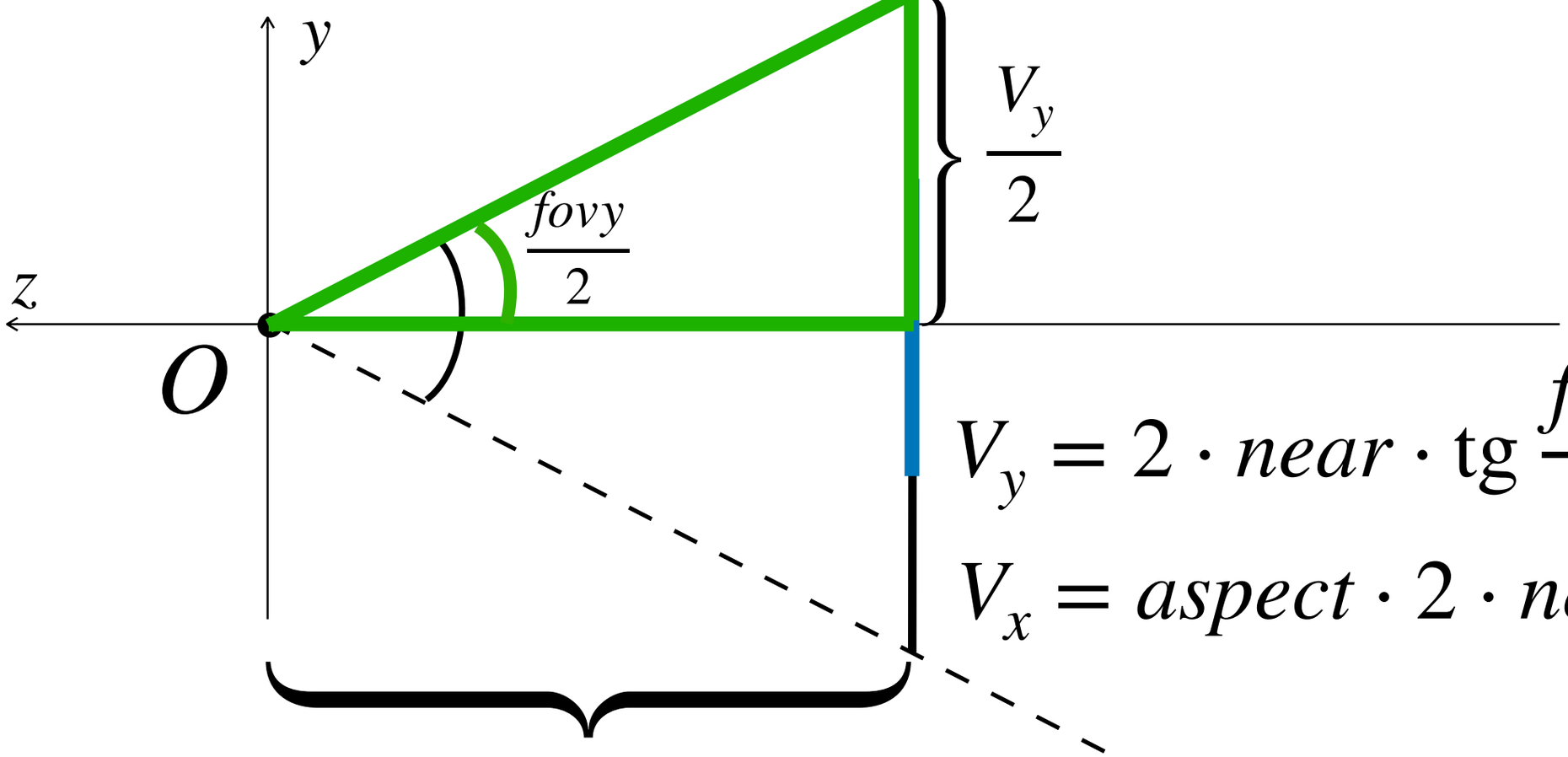


$$\frac{fovy}{aspect} = \frac{V_x}{V_y}$$

near

far

Матрица перспективного преобразования



$$V_y = 2 \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$V_x = aspect \cdot 2 \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$left = -aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$right = aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$bottom = -near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$top = near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$fovy$$

$$aspect = \frac{V_x}{V_y}$$

$$near$$

$$far$$

Матрица перспективного преобразования

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ 0 & 0 & -\frac{far + near}{far - near} & \frac{-2 \cdot far \cdot near}{far - near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$Frustum(left, right, bottom, top, near, far)$$

Матрица перспективного преобразования

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{2 \cdot near}{right - left} & 0 & \frac{right + left}{right - left} & 0 \\ 0 & \frac{2 \cdot near}{top - bottom} & \frac{top + bottom}{top - bottom} & 0 \\ 0 & 0 & -\frac{far + near}{far - near} & \frac{-2 \cdot far \cdot near}{far - near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$left = -\, aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2} \qquad right - left = 2 \cdot aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$right = aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2} \qquad right + left = 0$$

$$bottom = -\, near \cdot \operatorname{tg} \frac{fovy}{2} \qquad top - bottom = 2 \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$top = near \cdot \operatorname{tg} \frac{fovy}{2} \qquad top + bottom = 0$$

Матрица перспективного преобразования

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{1}{aspect \cdot \operatorname{tg} \frac{fovy}{2}} & 0 & 0 & 0 \\ 0 & \frac{1}{\operatorname{tg} \frac{fovy}{2}} & 0 & 0 \\ 0 & 0 & -\frac{far + near}{far - near} & \frac{-2 \cdot far \cdot near}{far - near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$left = -\, aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2} \qquad right - left = 2 \cdot aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$right = aspect \cdot near \cdot \operatorname{tg} \frac{fovy}{2} \qquad right + left = 0$$

$$bottom = -\, near \cdot \operatorname{tg} \frac{fovy}{2} \qquad top - bottom = 2 \cdot near \cdot \operatorname{tg} \frac{fovy}{2}$$

$$top = near \cdot \operatorname{tg} \frac{fovy}{2} \qquad top + bottom = 0$$

Матрица перспективного преобразования

$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{1}{aspect}\operatorname{ctg}\frac{fovy}{2} & 0 & 0 & 0 \\ 0 & \operatorname{ctg}\frac{fovy}{2} & 0 & 0 \\ 0 & 0 & -\frac{far+near}{far-near} & \frac{-2\cdot far\cdot near}{far-near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$left = -\,aspect\cdot near\cdot \operatorname{tg}\frac{fovy}{2} \qquad right - left = 2\cdot aspect\cdot near\cdot \operatorname{tg}\frac{fovy}{2}$$

$$right = aspect\cdot near\cdot \operatorname{tg}\frac{fovy}{2} \qquad right + left = 0$$

$$bottom = -\,near\cdot \operatorname{tg}\frac{fovy}{2} \qquad top - bottom = 2\cdot near\cdot \operatorname{tg}\frac{fovy}{2}$$

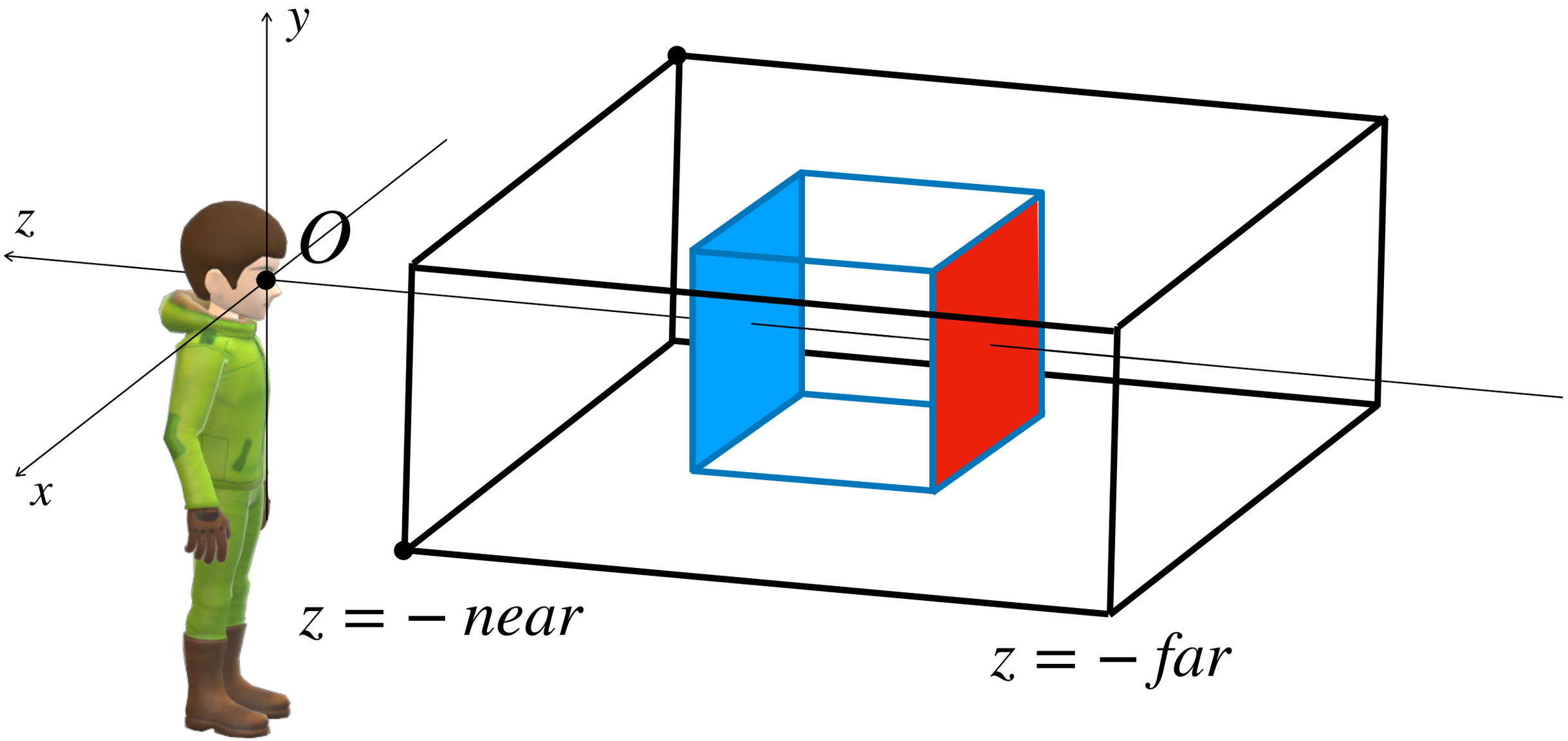
$$top = near\cdot \operatorname{tg}\frac{fovy}{2} \qquad top + bottom = 0$$

Матрица перспективного преобразования

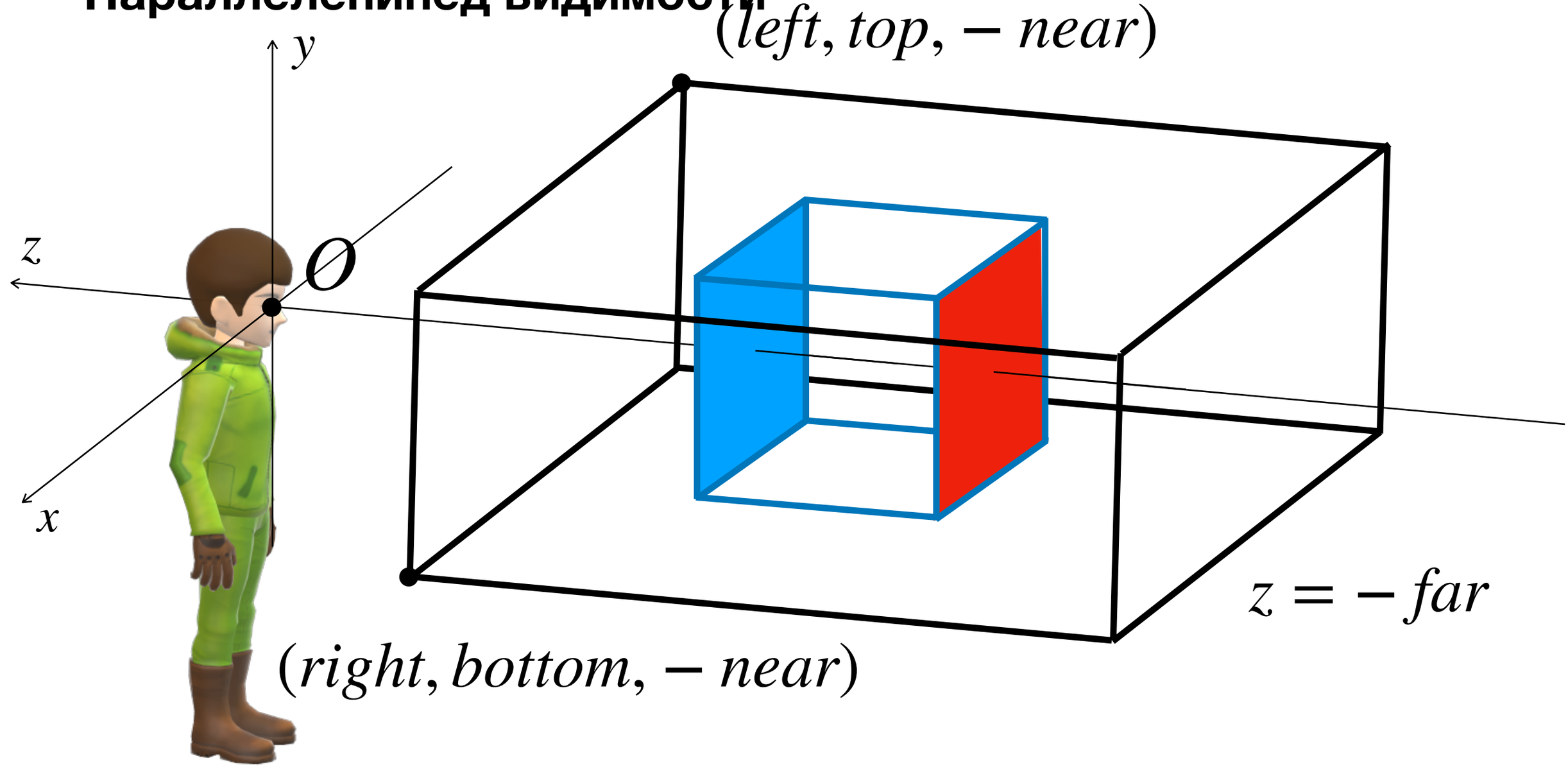
$$\begin{bmatrix} \chi'' \\ \gamma'' \\ \zeta'' \\ \alpha'' \end{bmatrix} = \begin{bmatrix} \frac{1}{aspect}\operatorname{ctg}\frac{fovy}{2} & 0 & 0 & 0 \\ 0 & \operatorname{ctg}\frac{fovy}{2} & 0 & 0 \\ 0 & 0 & -\frac{far+near}{far-near} & \frac{-2\cdot far\cdot near}{far-near} \\ 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$Perspective(fovy, aspect, near, far)$$

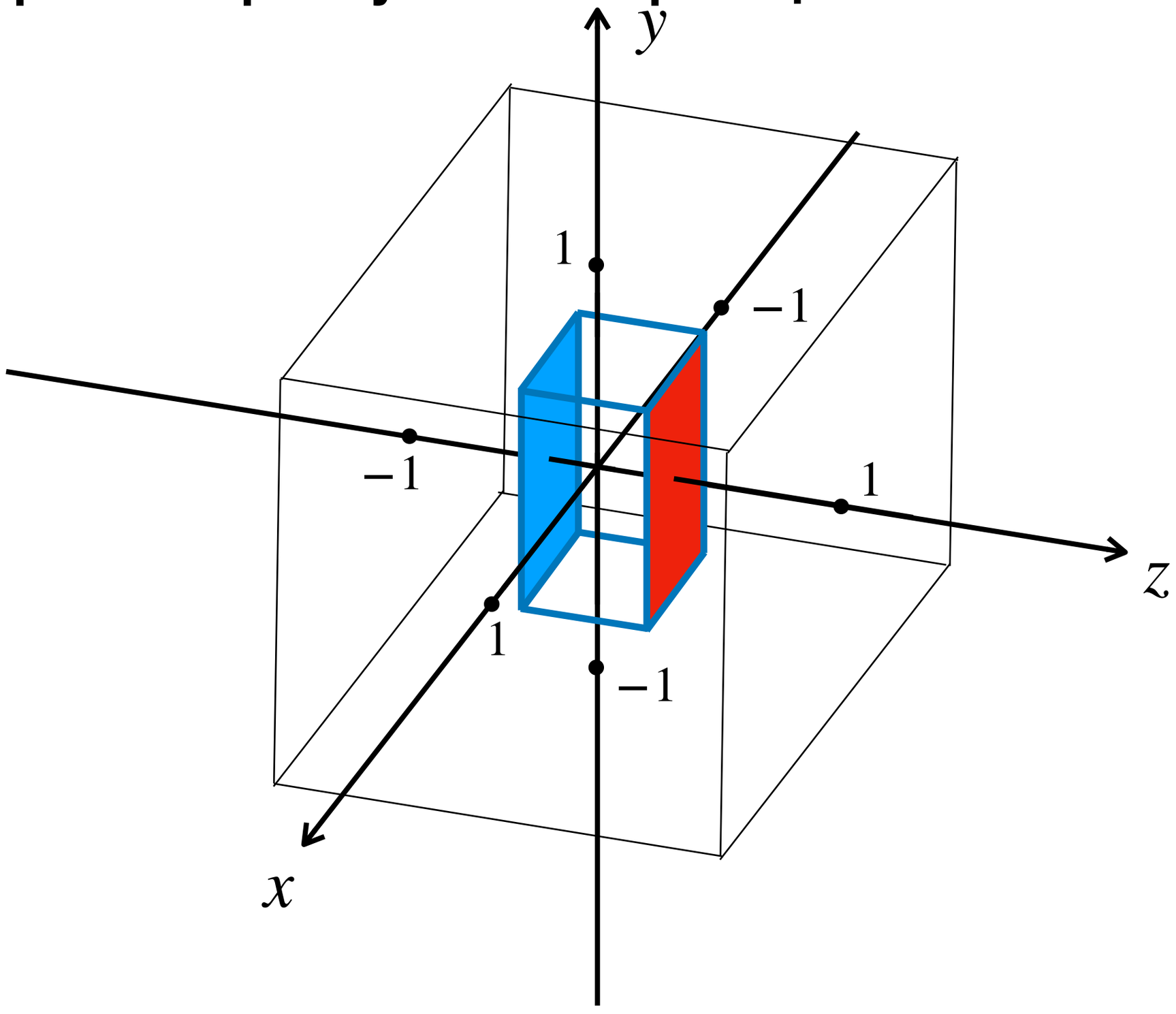
Параллелепипед видимости



Параллелепипед видимости



Построение прямоугольной проекции



Построение прямоугольной проекции

$$V_{cx} = left$$
$$V_{cy} = bottom$$
$$V_x = right - left$$
$$V_y = top - bottom$$
$$V_{cz} = -near$$
$$V_z = far - near$$
$$W_{cz} = -1$$
$$W_z = 2$$

$$W_{cx} = -1$$
$$W_{cy} = -1$$
$$W_x = 2$$
$$W_y = 2$$

$$x' = \frac{x - left}{right - left} \cdot 2 - 1$$
$$y' = \frac{y - bottom}{top - bottom} \cdot 2 - 1$$
$$z' = -1 - \frac{z + near}{far - near} \cdot 2$$

Построение прямоугольной проекции

$$x' = \frac{2x - 2 \cdot left - right + left}{right - left}$$

$$x' = x\frac{2}{right - left} - \frac{right + left}{right - left}$$

$$y' = \frac{2y - 2 \cdot bottom - top + bottom}{top - bottom}$$

$$y' = y\frac{2}{top - bottom} - \frac{top + bottom}{top - bottom}$$

Построение прямоугольной проекции

$$V_{cx} = left$$
$$V_{cy} = bottom$$
$$V_x = right - left$$
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$$x' = \frac{x - left}{right - left} \cdot 2 - 1$$
$$y' = \frac{y - bottom}{top - bottom} \cdot 2 - 1$$
$$z' = -1 - \frac{z + near}{far - near} \cdot 2$$

Построение прямоугольной проекции

$$x' = x\frac{2}{right - left} - \frac{right + left}{right - left}$$

$$y' = y\frac{2}{top - bottom} - \frac{top + bottom}{top - bottom}$$

$$z' = \frac{-far + near - 2z - 2 \cdot near}{far - near}$$

$$z' = z\frac{-2}{far - near} - \frac{far + near}{far - near}$$

Построение прямоугольной проекции

$$x' = x\frac{2}{right - left} - \frac{right + left}{right - left}$$

$$y' = y\frac{2}{top - bottom} - \frac{top + bottom}{top - bottom}$$

$$z' = z\frac{-2}{far - near} - \frac{far + near}{far - near}$$

Матрица прямоугольной проекции

$$\begin{bmatrix} \chi' \\ \gamma' \\ \zeta' \\ \alpha' \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$x' = x\frac{2}{right - left} - \frac{right + left}{right - left}$$

$$y' = y\frac{2}{top - bottom} - \frac{top + bottom}{top - bottom}$$

$$z' = z\frac{-2}{far - near} - \frac{far + near}{far - near}$$

Матрица прямоугольной проекции

$$\begin{bmatrix} \chi' \\ \gamma' \\ \zeta' \\ \alpha' \end{bmatrix} = \begin{bmatrix} \frac{2}{right-left} & 0 & 0 & -\frac{right+left}{right-left} \\ 0 & \frac{2}{top-bottom} & 0 & -\frac{top+bottom}{top-bottom} \\ 0 & 0 & \frac{-2}{far-near} & -\frac{far+near}{far-near} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$x' = x\frac{2}{right-left} - \frac{right+left}{right-left}$$

$$y' = y\frac{2}{top-bottom} - \frac{top+bottom}{top-bottom}$$

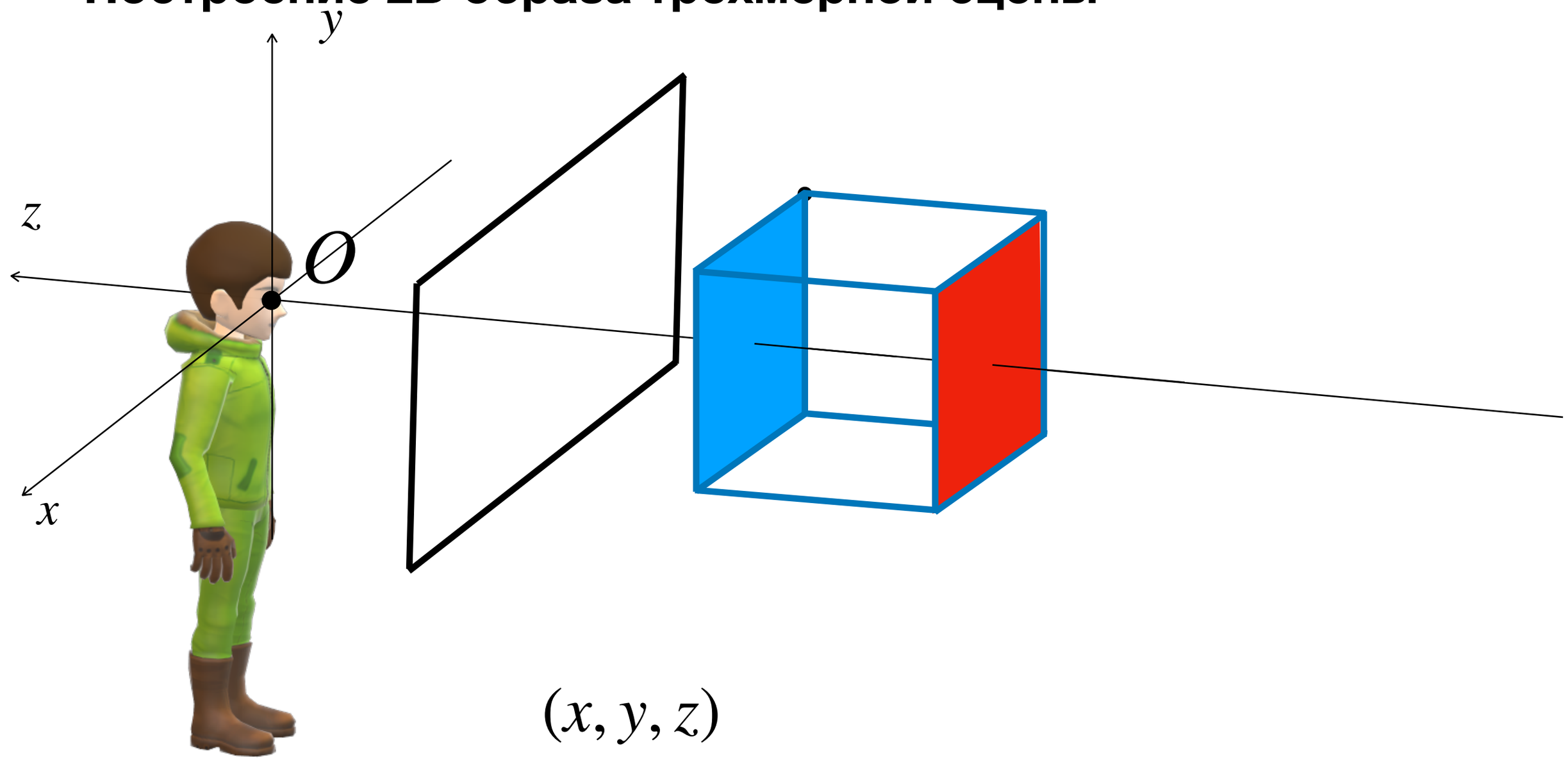
$$z' = z\frac{-2}{far-near} - \frac{far+near}{far-near}$$

Матрица прямоугольной проекции

$$\begin{bmatrix} \chi' \\ \gamma' \\ \zeta' \\ \alpha' \end{bmatrix} = \begin{bmatrix} \frac{2}{right-left} & 0 & 0 & -\frac{right+left}{right-left} \\ 0 & \frac{2}{top-bottom} & 0 & -\frac{top+bottom}{top-bottom} \\ 0 & 0 & \frac{-2}{far-near} & -\frac{far+near}{far-near} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix}$$

$$Ortho(left, right, bottom, top, near, far)$$

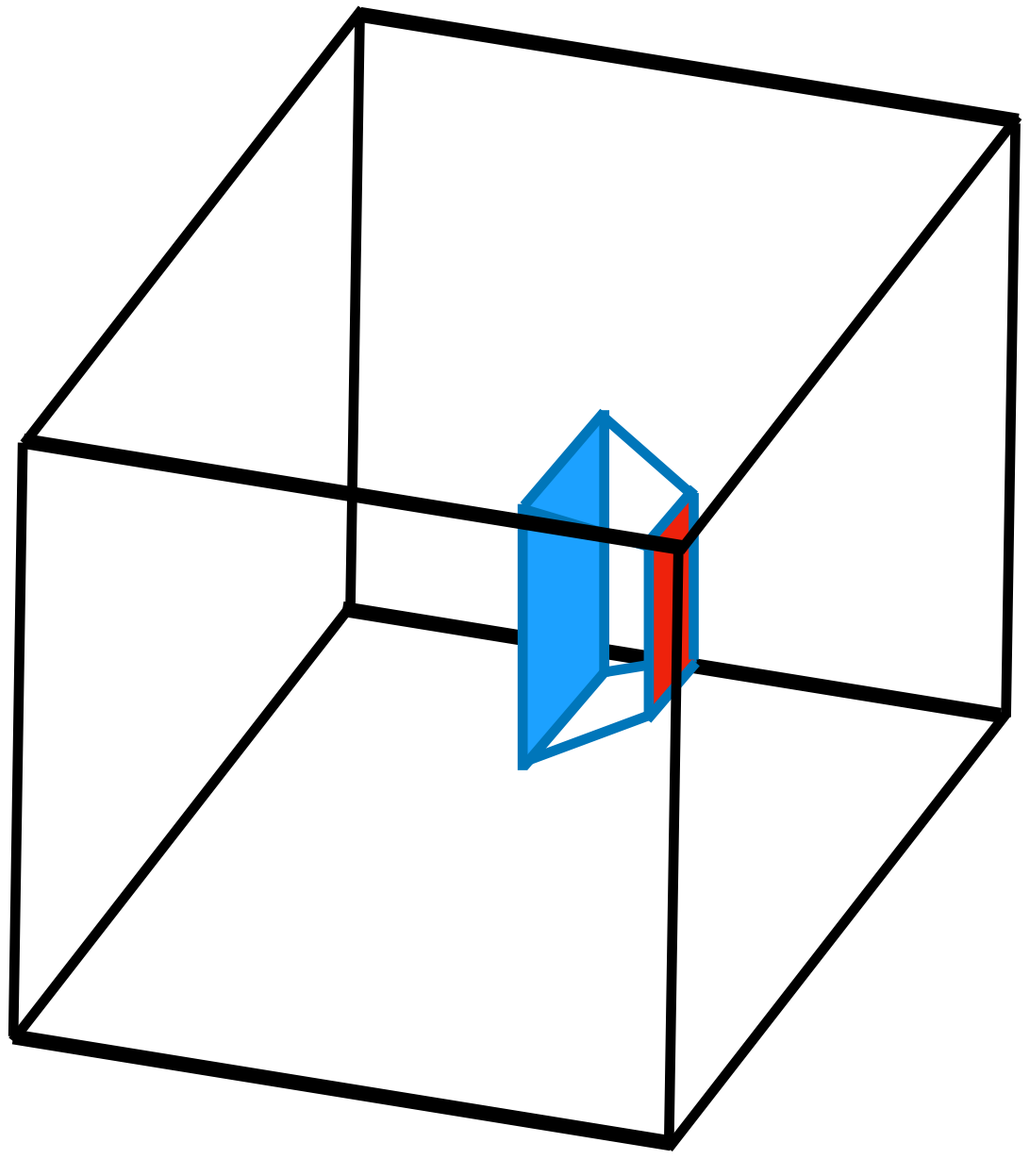
Построение 2D образа трехмерной сцены



$$(x, y, z)$$

$$(x, y, z, 1)$$

Построение 2D образа трехмерной сцены



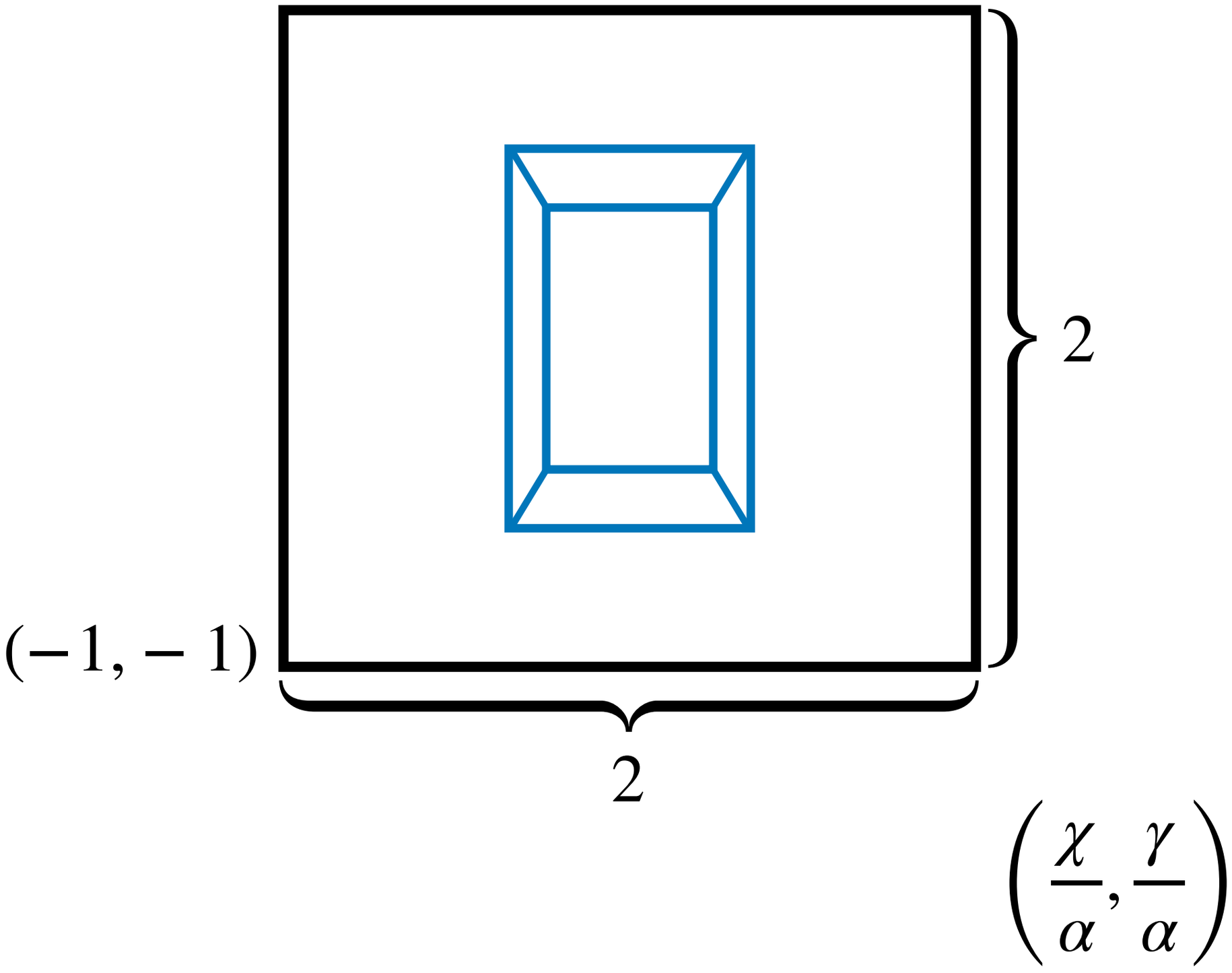
$(x, y, z, 1)$

$(\chi, \gamma, \zeta, \alpha)$

$$\left(\frac{\chi}{\alpha}, \frac{\gamma}{\alpha}, \frac{\zeta}{\alpha}\right)$$

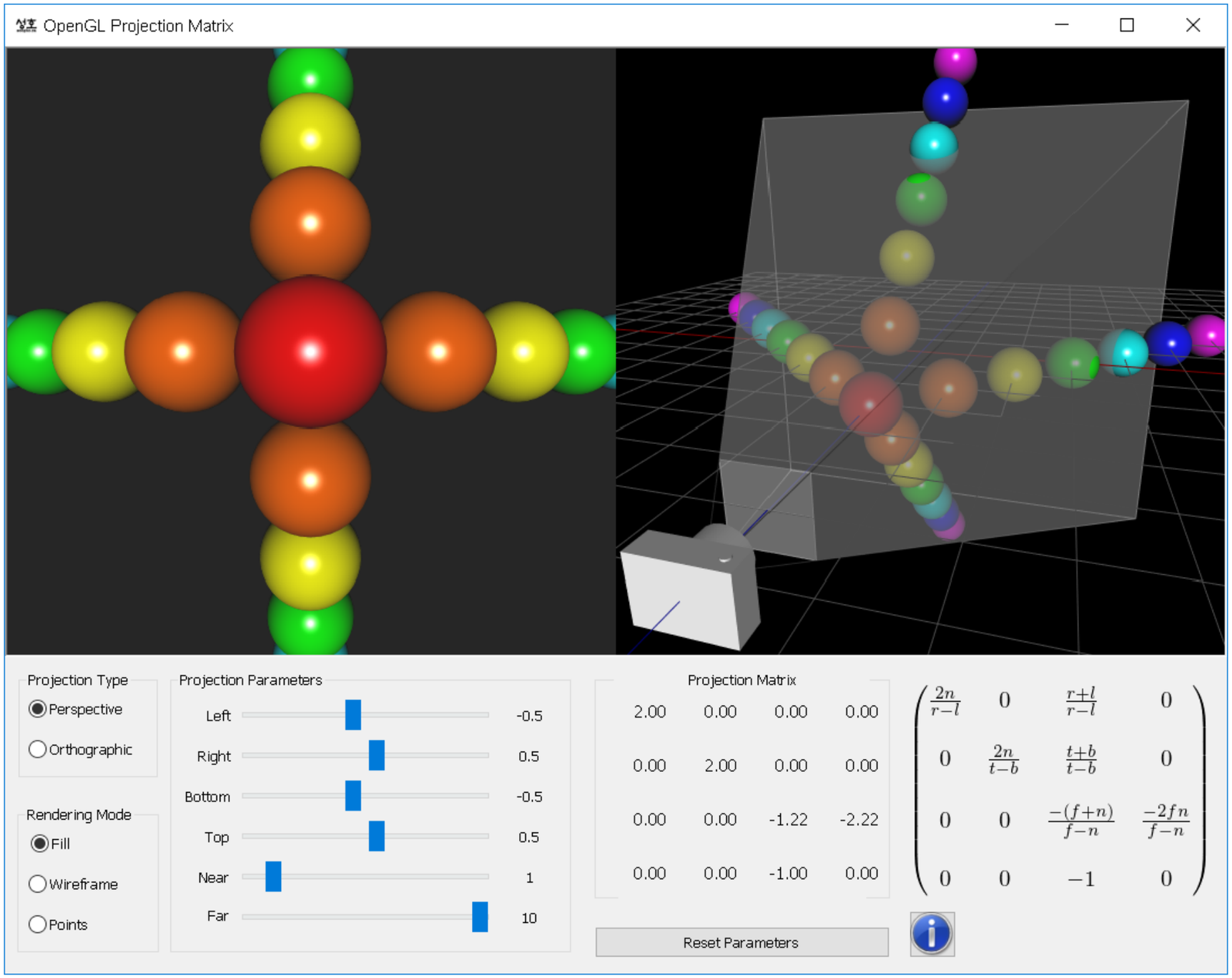
$$\left(\frac{\chi}{\alpha}, \frac{\gamma}{\alpha}\right)$$

Построение 2D образа трехмерной сцены



$$\left(\frac{\chi}{\alpha}, \frac{\gamma}{\alpha}\right)$$

Демонстрация движения наблюдателя (камеры) в пространстве



Программа “OpenGL Projection Matrix” демонстрирует влияние выбора параметров матрицы проекции на получаемое изображение.
Переключатель “Projection Type” реализует выбор между прямоугольной и перспективной проекцией.
Изменение значений “Projection Parameters” влияет на размеры пирамиды/параллелепипеда видимости.
Программа доступна на сайте http://www.songho.ca/opengl/gl_transform.html