# Video Digitization

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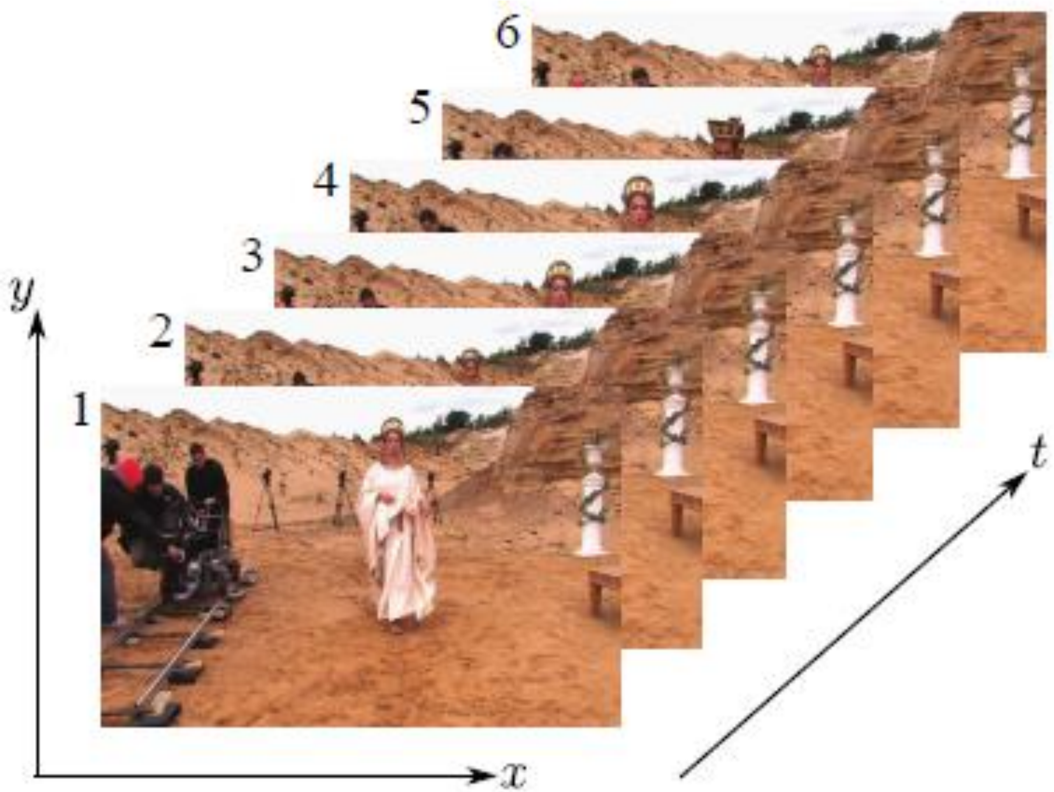
# Video Digitization

- **3D data types**
- Video sampling
- Progressive video sampling
- General video sampling grids
- General analog video reconstruction

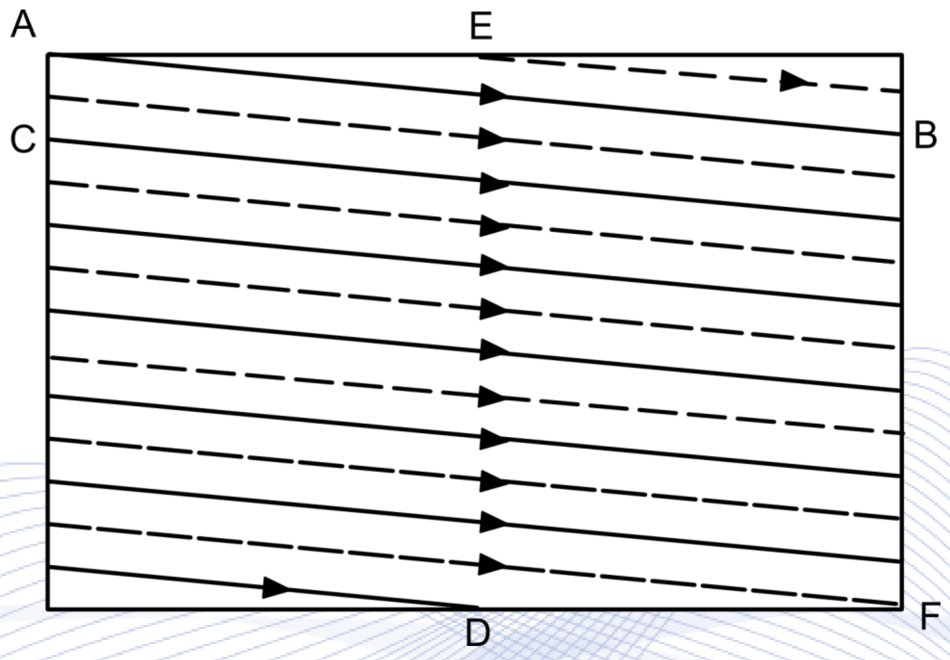
# 3D data types: video



# 3D data types: video

- ***Moving images*** are ***spatiotemporal 3D signals*** of the form: $f(x, y, t): \mathbb{R}^3 \rightarrow \mathbb{R}$, having:
  - domain $\mathbb{R}^3$ and codomain $\mathbb{R}$.
  - the time $t$ coordinate has a different nature than the spatial coordinates $x, y$.
- ***Video scanning***: creation of an 1D analog video signal, by sampling the time-varying images (luminance or RGB channels) along the vertical axis $y$ and time $t$.

# 3D data types: video




Analog video scanning.

# 3D data types: video, cinema

- Analog video signal $f(x, j\Delta y, k\Delta t)$: $\mathbb{R} \times \mathbb{Z}^2 \rightarrow \mathbb{R}$.
  - discrete along $y$ and $t$ axes
  - continuous along $x$ axis.
- Cinema moving images $f(x, y, k\Delta t)$: $\mathbb{R}^2 \times \mathbb{Z} \rightarrow \mathbb{R}$.
- Digital video signal $f(i\Delta x, j\Delta y, k\Delta t)$: $\mathbb{Z}^3 \rightarrow \mathbb{R}$.

# 3D data types: video, cinema

- ***Spatial sampling intervals*** $\Delta x, \Delta y$ define ***image resolution***: the smaller they are, the smaller the pixel size is.
  - ***HDTV image resolution*** 1080p: $1080 \times 1920$ pixels.

- ***Temporal sampling interval*** $\Delta t$ defines the ***video frame rate*** in ***frames per second*** (***fps***).
  - Typical fps: 25 (Europe), 30 (USA).

# 3D data types: volumetric images

- ***3D volumetric images***: 3D signals of the form:

$$f(x, y, z):\ \ \mathbb{R}^3 \rightarrow \mathbb{R}.$$

- Discrete versions (defined on a Euclidean grid $\mathbb{Z}^3$):

$$f(n_1, n_2, n_3):\ \ \mathbb{Z}^3 \rightarrow \mathbb{R}.$$

- $x = n_1 \Delta x,\ \ y = n_2 \Delta y,\ \ z = n_3 \Delta z.$
- $\Delta x, \Delta y, \Delta z$: ***spatial sampling intervals*** define 3D image resolution.
- Each ***voxel*** is a real number.

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# 3D data types : volumetric images

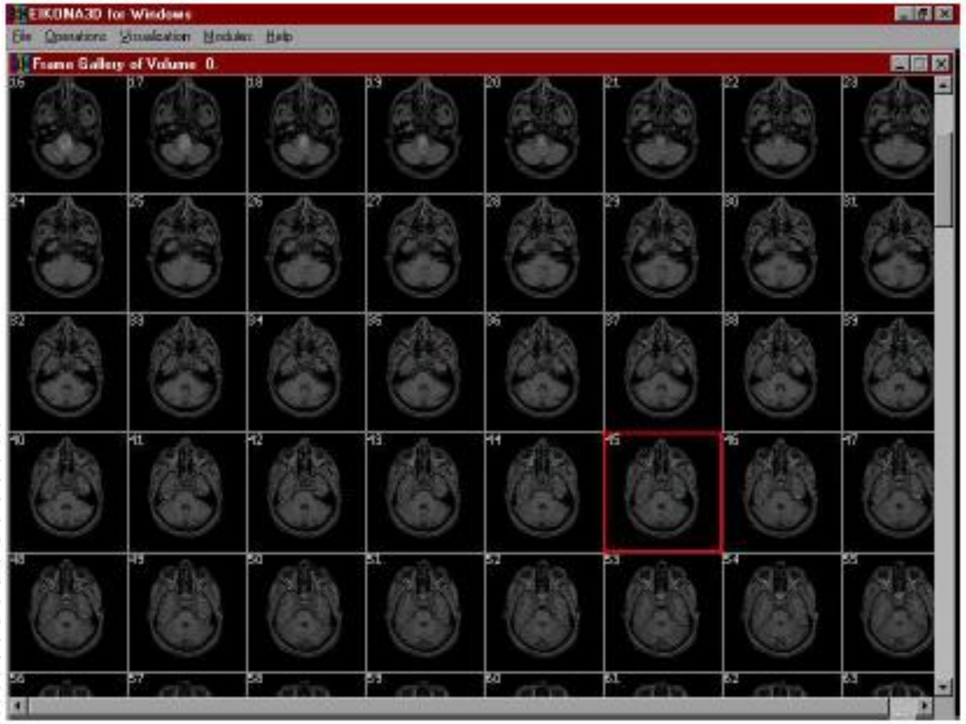



Image gallery of a 3D volume.

# 3D data types: multispectral images

- ***Multispectral/multichannel*** ($n$-channel) images have the form: $\boldsymbol{f}(x,y)\colon \mathbb{R}^2 \rightarrow \mathbb{R}^n$.
- Color images ($n=3$):

$$\boldsymbol{f}(x,y) = [f_R(x,y), f_G(x,y), f_B(x,y)]^T\colon \quad \mathbb{R}^2 \rightarrow \mathbb{R}^3.$$

- Digital color images (assigning 8 bits per color channel to each pixel): $\boldsymbol{f}(n_1,n_2)\colon \mathbb{Z}^2 \rightarrow \{0,\dots,255\}^3$.
- They are also 3D images $f(n_1,n_2,i)$, $\quad i = 1,2,3$.
- ***Hyperspectral images*** (3D images): $f(x,y,\lambda)\colon \mathbb{R}^3 \rightarrow \mathbb{R}$.
  - $\lambda$ wavelength.

# 3D data types: memory issues

- 3D volumetric images have relatively small number of 3D image slices.
- Video has very large number of video frames:
  - 1 hour video: $60 \times 60 \times 50 = 180{,}000$ video frames.
- High frame rates: 25/50 up to 1000 Hz.
  - Use in recording high-speed phenomena.
- ***Video buffering***:
  - Only few video frames are stored in RAM.
  - Buffer update in live streams.

# 3D data types

- ***Multiview images***: images of an object or set, taken from different view points, typically using different cameras.
  - ***Stereo images***: a special case, employing only two cameras (left and right).
  - Video synchronization issues.

# 3D data types

- They both carry only implicit geometrical information about the visualized 3D object.
  - They are ***not*** 3D data.
  - 3D object geometry can be derived using stereo or multiview 3D geometry reconstruction techniques.

# 3D data types

Multiview video captured by synchronized video-cameras.

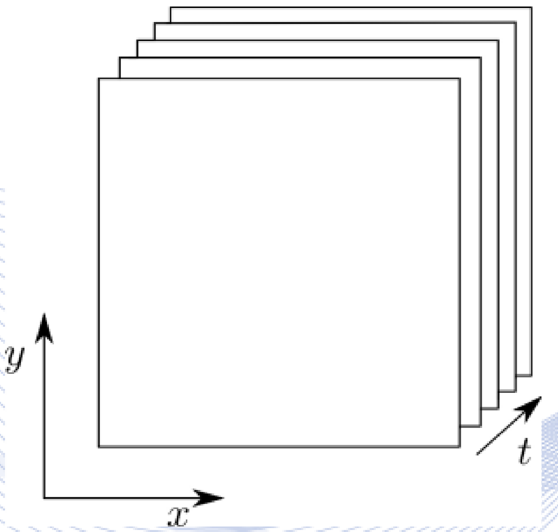
# Video Digitization

- 3D data types
- **Video sampling**
- Progressive video sampling
- General video sampling grids
- General analog video reconstruction

# Video sampling

- Analog video signal is an image sequence $f(x, y, t)$.
  - $x$: horizontal coordinate,
  - $y$: vertical coordinate,
  - $t$: time coordinate.
- Digital video signal is obtained

by spatiotemporal sampling of analog video along its coordinates $x, y, t$.




Spatiotemporal video signal.

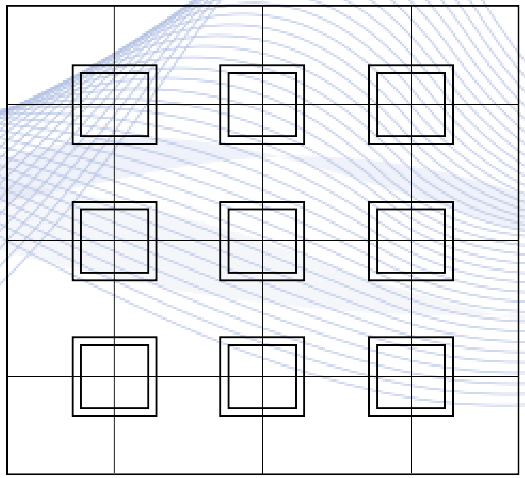
# Video sampling

- ***Analog video scanning***:
  - 3D luminance signal is scanned along the horizontal axis $x$ and then over time $t$.
  - During analog video transmission, 1D signals $f(x, j\Delta y, \kappa\Delta t)$ are concatenated to form an 1D analog signal as a function of time that can be broadcasted.
- The analog video signal is discrete along axes $y, t$ and continuous along axis $x$.

# Video sampling

- Digital video can be obtained:
  - by sampling analog video along the horizontal scan lines,
  - by using the discrete 2D sampling grid inherent in photoelectric sensors, e.g., in CCD chips.

CCD chip.



# Video Digitization

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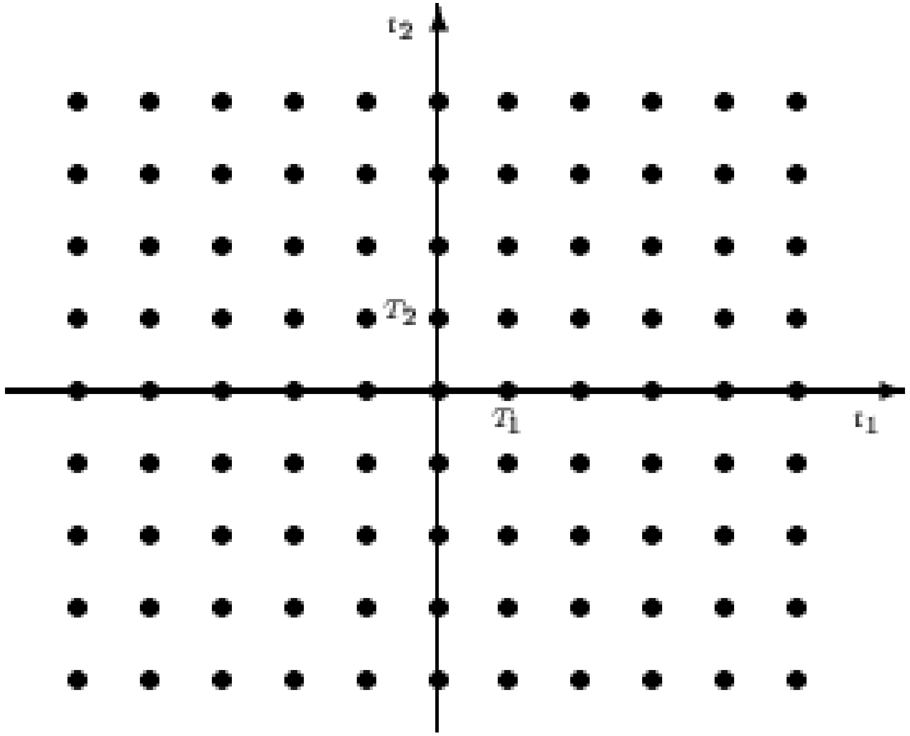
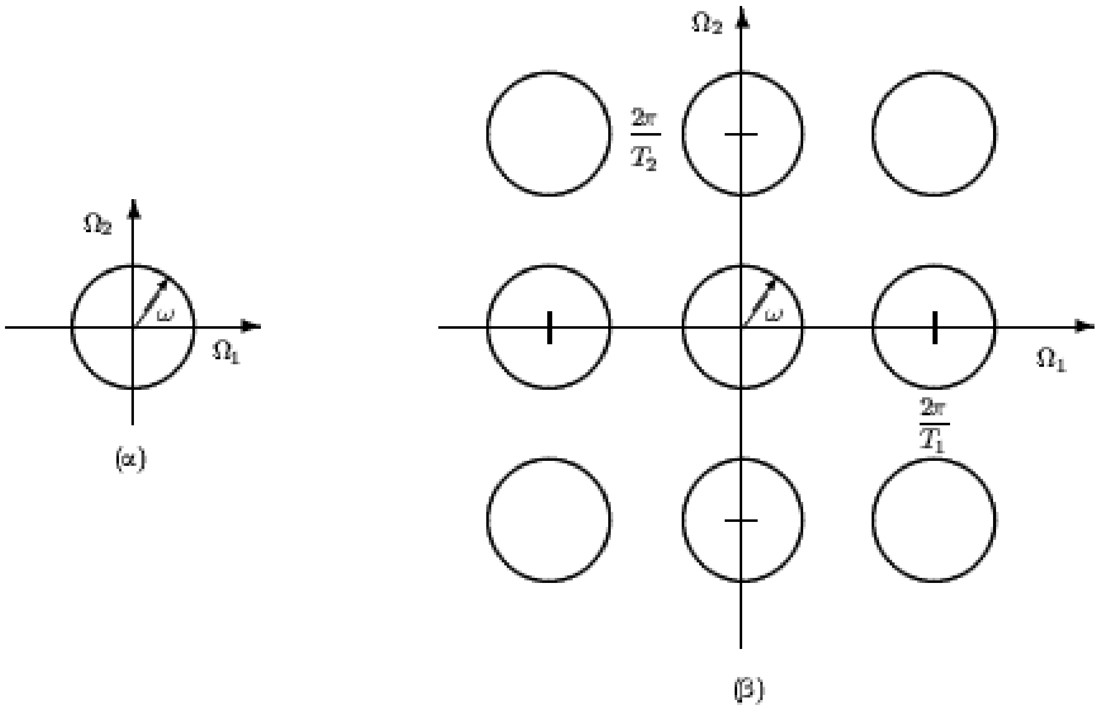
# 2D image sampling




Rectangular image sampling grid.

# 2D sampled image spectrum

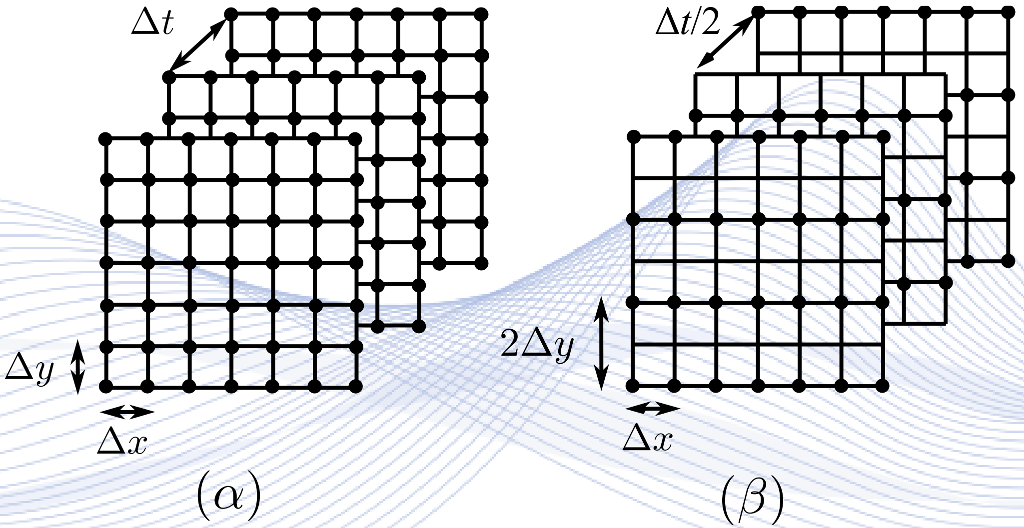



Fourier Transform of: a) Analog image; b) Discrete image.

# Progressive video sampling

***Progressive sampling***:

- uniform spatiotemporal analog video sampling along $x, y, t$.




Sampling grids for: a) Progressive; b) 2:1 interlaced video.

# Progressive video spectrum

Discrete (sampled) video $f(n_1, n_2, n_t)$:

$$f(n_1, n_2, n_t) = f_a(n_1 \Delta x, n_2 \Delta y, n_t \Delta t).$$

- $f_a(x, y, t)$: analog spatiotemporal video signal.
- $\Delta x, \Delta y, \Delta t$: sampling intervals along the horizontal/vertical spatial axis $x$, $y$ and time axis $t$.

# Progressive video sampling

Forward and inverse ***3D Fourier transform*** of analog video:

$$F_a(\Omega_x,\Omega_y,\Omega_t) = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f_a(x,y,t)e^{-i\Omega_x x - i\Omega_y y - i\Omega_t t}\, dxdydt,$$

$$f_a(x,y,t) = \frac{1}{(2\pi)^3}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} F_a(\Omega_x,\Omega_y,\Omega_t)e^{i\Omega_x x + i\Omega_y y + i\Omega_t t}\, d\Omega_x d\Omega_y d\Omega_t\,.$$

- $\Omega_x = 2\pi F_x,\ \Omega_y = 2\pi F_y,\ \ \Omega_t = 2\pi F_t$: ***spatiotemporal frequencies***.
- They describe video content variations over space/time.

# Progressive video spectrum

- Smooth video content is represented by low frequency content:
  - ***DC term***: $\mathbf{\Omega}^T = \left[\Omega_x, \Omega_y, \Omega_t\right]^T = [0,0,0]^T$ dominates.
- Image details and video content changes along $x, y$ axis lead to high spatial frequency $\Omega_x$, $\Omega_y$ content:
  - Edges, lines, textured regions.
- Fast video content changes over time lead to high $\Omega_t$ frequency content:
  - e.g., in the case of fast moving objects.

# Progressive video spectrum

***3D discrete spatiotemporal Fourier transform***:

$$F(\omega_x, \omega_y, \omega_t) = \sum_{n_1}\sum_{n_2}\sum_{n_3} f(n_1, n_2, n_t)e^{-i(\omega_x n_1 + \omega_y n_2 + \omega_t n_t)} \quad (4)$$

and:

$$f(n_1, n_2, n_3) = \left(\frac{1}{2\pi}\right)^3 \int_{-\pi}^{\pi}\int_{-\pi}^{\pi}\int_{-\pi}^{\pi} F(\omega_x, \omega_y, \omega_t)\, e^{i(\omega_x n_1 + \omega_y n_2 + \omega_t n_t)} d\omega_x d\omega_y d\omega_t \quad (5)$$

- $\omega_x = \Omega_x \Delta x, \ \ \omega_y = \Omega_y \Delta y, \ \ \omega_t = \Omega_t \Delta t.$
- they are defined on a unit circle: $\omega_x, \omega_y, \omega_t \in [-\pi, \pi]$.

# Progressive video spectrum

- The triple integral can divided into a triple sum of integrals:

$$f(n_1, n_2, n_t) = \frac{1}{(2\pi)^3} \sum_{k_x} \sum_{k_y} \sum_{k_t} \int \int \int_{RP(k_x,k_y,k_t)} \frac{1}{\Delta x \Delta y \Delta t} F_a\left(\frac{\omega_x}{\Delta x}, \frac{\omega_y}{\Delta y}, \frac{\omega_t}{\Delta t}\right) e^{i\omega_x n_1 + i\omega_y n_2 + i\omega_t n_t} d\omega_x d\omega_y d\omega_t.$$

- Each of them is defined on the shifted parallelepipeds $RP(k_x, k_y, k_t)$:

$$-\pi + 2\pi k_x \leq \omega_x \leq \pi + 2\pi k_x,$$
$$-\pi + 2\pi k_y \leq \omega_y \leq \pi + 2\pi k_y,$$
$$-\pi + 2\pi k_t \leq \omega_t \leq \pi + 2\pi k_t.$$

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# Progressive video spectrum

- By interchanging summations with integrals and changing variables, the 3D discrete spatiotemporal Fourier transform is given by:

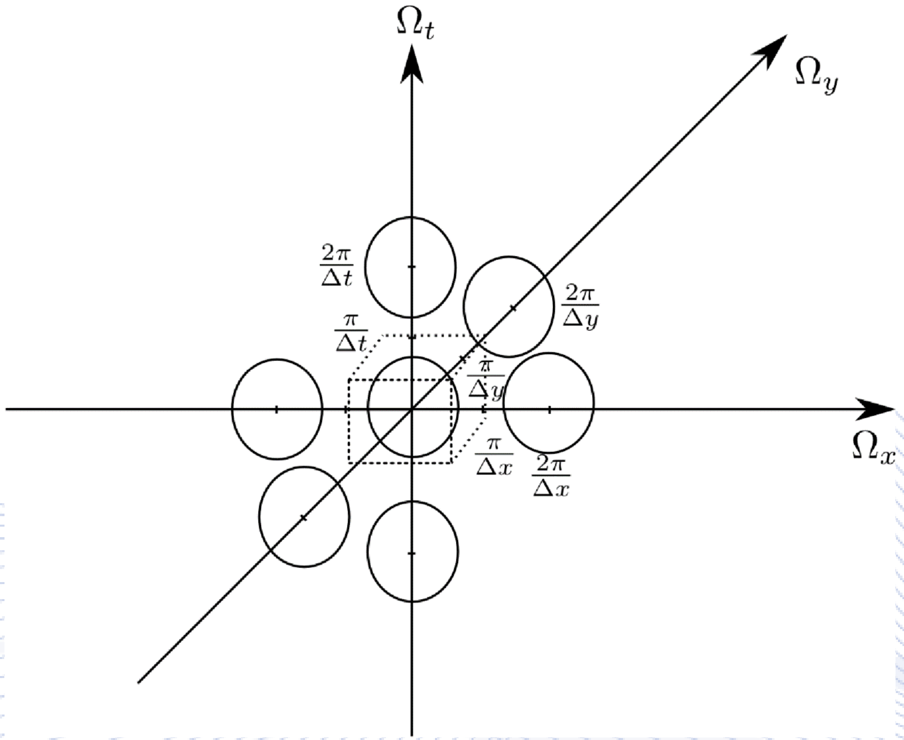
$$F(\omega_x, \omega_y, \omega_t) = \frac{1}{\Delta x \Delta y \Delta t} \sum_{k_x} \sum_{k_y} \sum_{k_t} F_a\left(\frac{\omega_x - 2\pi k_x}{\Delta x}, \frac{\omega_y - 2\pi k_y}{\Delta y}, \frac{\omega_t - 2\pi k_t}{\Delta t}\right),$$

or

$$F(\Omega_x \Delta_x, \Omega_y \Delta_y, \Omega_t \Delta_t) = \frac{1}{\Delta x \Delta y \Delta t} \sum_{k_x} \sum_{k_y} \sum_{k_t} F_a\left(\Omega_x - \frac{2\pi k_x}{\Delta x}, \Omega_y - \frac{2\pi k_y}{\Delta y}, \Omega_t - \frac{2\pi k_t}{\Delta x}\right).$$

- Periodic translation of the 3D Fourier transform $F_a(\Omega_x, \Omega_y, \Omega_t)$ of the analog video $f_a(x, y, t)$.

# Progressive video spectrum




3D periodic translation of the analog video spectrum.

# Progressive video spectrum

If the sampling intervals $\Delta x$, $\Delta y$, $\Delta t$ are sufficiently small, so that:

$$F\left(\Omega_x \Delta x, \Omega_y \Delta y, \Omega_t \Delta t\right) = 0, \quad |\Omega_x| \geq \frac{\pi}{\Delta x}, \left|\Omega_y\right| \geq \frac{\pi}{\Delta y}, |\Omega_t| \geq \frac{\pi}{\Delta t}.$$

the discrete video spectrum is given by the periodic translation of the fundamental period:

$$F\left(\Omega_x \Delta x, \Omega_y \Delta y, \Omega_t \Delta t\right) = \frac{1}{\Delta x \Delta y \Delta t} F_a\left(\Omega_x, \Omega_y, \Omega_t\right),$$

$$|\Omega_x| \leq \frac{\pi}{\Delta x}, \left|\Omega_y\right| \leq \frac{\pi}{\Delta y}, |\Omega_t| \leq \frac{\pi}{\Delta t}.$$

# Reconstruction of analog video

Analog video can be reconstructed from the discrete video:

$$f_a(x,y,t) = \sum_{n_1}\sum_{n_2}\sum_{n_t} f(n_1,n_2,n_t)\frac{\sin\frac{\pi}{\Delta x}(x-n_1\Delta x)}{\frac{\pi}{\Delta x}(x-n_1\Delta x)}\frac{\sin\frac{\pi}{\Delta y}(y-n_2\Delta y)}{\frac{\pi}{\Delta y}(y-n_2\Delta y)}\frac{\sin\frac{\pi}{\Delta t}(t-n_t\Delta t)}{\frac{\pi}{\Delta t}(t-n_t\Delta t)}.$$

- Mathematical modeling of digital video visualization/ projection.
- In reality, much simpler approaches are used:
  - Zero-order interpolation
  - Square image blobs can be visible.

# Reconstruction of analog video

- If $\Delta x, \Delta y, \Delta t$ are sufficiently small, analog video can be precisely reconstructed.
- If the video signal is not low-pass:
  - too many image details and/or very strong motion.
- or the sampling intervals $\Delta x, \Delta y, \Delta t$ are not sufficiently small, ***spectrum aliasing*** occurs.

# Reconstruction of analog video

- Spectrum content overlaps in high frequency areas:

$$|\Omega_x \Delta x| \leq \pi, \quad |\Omega_y \Delta y| \leq \pi, \quad |\Omega_t \Delta x| \leq \pi.$$

- High frequency video content is smoothed out (details and strong motion).

# Reconstruction of analog video

- ***Nyquist criterion***:

$$\Delta x \leq \frac{\pi}{\Omega_{xmax}}, \quad \Delta y \leq \frac{\pi}{\Omega_{ymax}}, \quad \Delta t \leq \frac{\pi}{\Omega_{tmax}},$$

to avoid aliasing problems.

- ***Sampling frequencies*** $F_{sx} = \frac{1}{\Delta x}, F_{sy} = \frac{1}{\Delta y}, F_{st} = \frac{1}{\Delta t}$ must satisfy:

$$F_{sx} \geq 2F_{xmax}, \quad F_{sy} \geq 2F_{ymax}, \quad F_{st} \geq 2F_{tmax}.$$

- $F_{xmax}, F_{ymax}, F_{tmax}$: maximal spatial and temporal video frequencies.

# Video Digitization

- 3D data types
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- **General video sampling grids**
- General analog video reconstruction

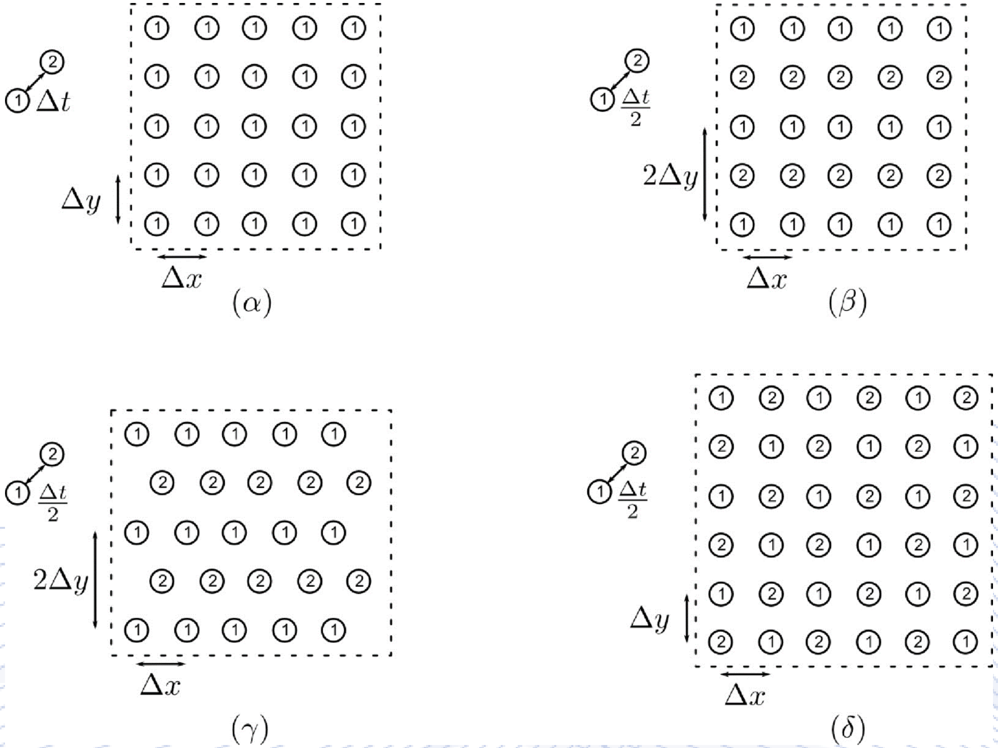
# General video sampling grids

- Multidimensional signal $f(\mathbf{x})$ over $\mathbb{R}^K$.
- Video: special multidimensional signal for $K = 3$.
- ***3D sampling grid***: mathematical structure describing video sampling (also called ***lattice***):

$$\Lambda = \left\{\mathbf{x} \in \mathbb{R}^K \;\middle|\; \mathbf{x} = \sum_{k=1}^{K} n_k \mathbf{v}_k, \quad \forall n_k \epsilon \mathbb{Z}\right\}.$$

- $\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_K$: Linearly independent basis vectors on $\mathbb{R}^K$.
- $\mathbf{V} = [\mathbf{v}_1, \dots, \mathbf{v}_K]$: ***sampling matrix***.

# General video sampling grids




a) Rectangular sampling grid; b) Vertically aligned interlaced grid; c) Quincunx grid; d) Orthorhombic grid.

# General video sampling grids

- Any grid point can be represented by vector:

$$\mathbf{n} = [n_1, n_2, \ldots, n_K] \in \mathbb{Z}^K.$$

- Actual pixel position in $\mathbb{R}^K$: $\mathbf{x} = \mathbf{V}\mathbf{n}$.
- Sampling matrix or basis vectors fully define a sampling grid.
- They are not unique:
- $\mathbf{V}$ and $\mathbf{V}' = \mathbf{E}\mathbf{V}$ define the same sampling grid $\Lambda$, if:
- $\mathbf{E}$: integer matrix and $\det(\mathbf{E}) = \pm 1$.

# General video sampling grids

- Progressive sampling grid matrix:

$$\mathbf{V} = \begin{bmatrix} \Delta x & 0 & 0 \\ 0 & \Delta y & 0 \\ 0 & 0 & \Delta t \end{bmatrix}.$$

- Vertically aligned interlaced grid matrix :

$$\mathbf{V} = \begin{bmatrix} \Delta x & 0 & 0 \\ 0 & 2\Delta y & \Delta y \\ 0 & 0 & \Delta t/2 \end{bmatrix}.$$

# General video sampling grids

- Quincunx grid matrix:

$$\mathbf{V} = \begin{bmatrix} \Delta x & 0 & \Delta x/2 \\ 0 & 2\Delta y & \Delta y \\ 0 & 0 & \Delta t/2 \end{bmatrix}.$$

- Orthorhombic grid matrix:

$$\mathbf{V} = \begin{bmatrix} 2\Delta x & \Delta x & \Delta x \\ 0 & \Delta y & 0 \\ 0 & 0 & \Delta t/2 \end{bmatrix}.$$

# General video sampling grids

- Each grid has a unit cell, whose definition is not unique.
- ***Unit grid cell*** (***Voronoi cell***) $\mathcal{V}(\Lambda)$: the set of points on $\mathbb{R}^K$ that are closest to $\mathbf{0}$, then to any other grid point:

$$\mathcal{V}(\Lambda) = \{\mathbf{x} \in \mathbb{R}^K | d(\mathbf{x}, \mathbf{0}) \leq d(\mathbf{x}, \mathbf{p}), \quad \forall \mathbf{p} \in \Lambda\}.$$

- $d(\mathbf{x}, \mathbf{p})$: Euclidean distance of points $\mathbf{x}, \mathbf{p} \in \mathbb{R}^K$.

# General video sampling grids

- ***Grid sampling density***: it is the number of grid nodes that exist in the unit volume in $\mathbb{R}^K$.

- It equals the inverse of the unit cell volume:

$$D(\Lambda) = \frac{1}{|\det \mathbf{V}|}.$$

# General video sampling grids

- ***Inverse grid*** $\Lambda^*$ is defined by the grid sampling matrix $\mathbf{U}$:

$$\mathbf{V}^T\mathbf{U} = 2\pi\mathbf{I}.$$

- ***Sampling grid density*** of the inverse grid $\Lambda^*$:

$$D(\Lambda^*) = \frac{1}{(2\pi)^3 D(\Lambda)} = \frac{|det\mathbf{V}|}{(2\pi)^3}.$$

- It is inversely proportional to that of the sampling lattice $\Lambda$.

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# General video sampling

- $f_a(\mathbf{x}_t)$, $\mathbf{x}_t = [x, y, t]^T \in \mathbb{R}^3$: analog video.
- Video sampling using sampling matrix $\mathbf{V}$:

$$f(\mathbf{n}) = f_a(\mathbf{x}_t) \sum_{n \in \mathbb{Z}^3} \delta(\mathbf{x}_t - \mathbf{V}\mathbf{n}).$$

- $\mathbf{n} = [n_1, n_2, n_t]^T \in \mathbb{Z}^3$.

# General video sampling

- Discrete spatiotemporal Fourier transform:

$$F(\boldsymbol{\omega}) = \sum_{\mathbf{n} \in \mathbb{Z}^3} f(\mathbf{n}) e^{i\boldsymbol{\Omega}^T \mathbf{V}\mathbf{n}},$$

- $\boldsymbol{\omega} = \mathbf{V}^T \boldsymbol{\Omega}$.
- $\mathbf{U} = 2\pi(\mathbf{V}^T)^{-1}$: sampling matrix the inverse grid $\Lambda^*$.
- If $\mathbf{n}^T \mathbf{k} = m \in \mathbb{Z}$, then $F(\boldsymbol{\omega} + 2\pi\mathbf{k}) = F(\boldsymbol{\omega})$.
- The Fourier transform of a sample video on a lattice $\Lambda$ is periodic on lattice $\Lambda^*$ on $\mathbb{R}^3$.

# General video sampling

- Discrete video spectrum:

$$F(\boldsymbol{\omega}) = \frac{1}{|\det \mathbf{V}|} \sum_{\mathbf{k} \epsilon \mathbb{Z}^3} F_a\left(\frac{1}{2\pi}\mathbf{U}(\boldsymbol{\omega} - 2\pi\mathbf{k})\right).$$

- Sampling grid $\Lambda$,
- Periodic translation of the analog video spectrum on the inverse grid $\Lambda^*$.

# General video sampling

***Spectrum aliasing***:

- The denser the sampling grid $\Lambda$ is, the more sparse is the inverse $\Lambda^*$ grid.

- If the support area of the continuous video signal spectrum is bigger than the unit cell $P$ of the grid $\Lambda^*$, the nearby areas of the translated spectrum version overlap.

- Alias reduction: use a denser sampling grid.

# General video sampling

- Progressive video frequency periodicity grid $\Lambda^*$:

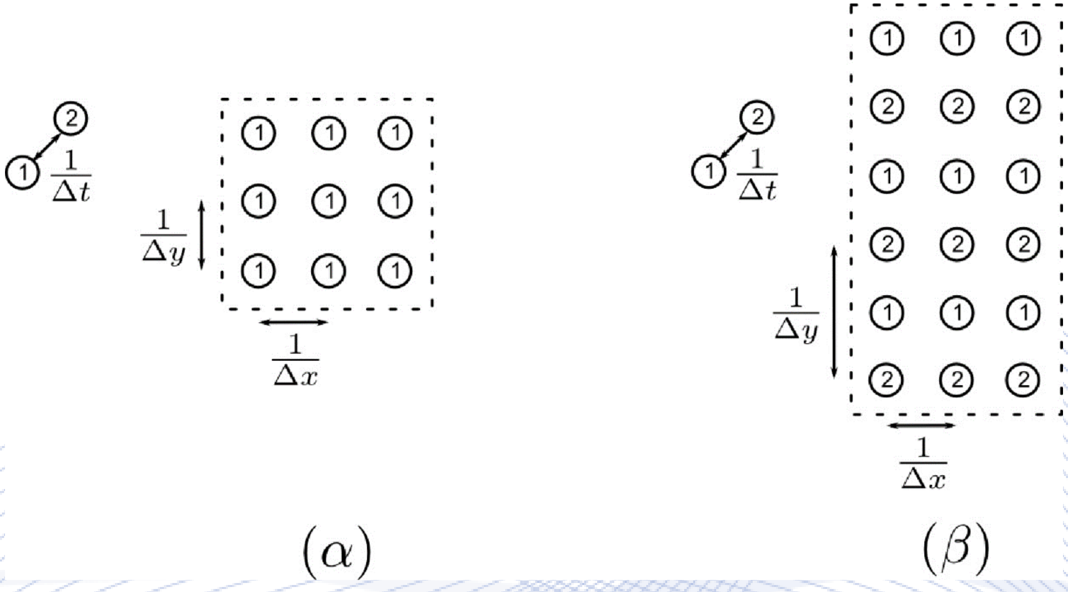
$$\mathbf{U} = 2\pi(\mathbf{V}^T)^{-1} = \begin{bmatrix} \frac{2\pi}{\Delta x} & 0 & 0 \\ 0 & \frac{2\pi}{\Delta y} & 0 \\ 0 & 0 & \frac{2\pi}{\Delta t} \end{bmatrix},$$

- 2:1 interlaced frequency periodicity grid $\Lambda^*$:

$$\mathbf{U} = 2\pi(\mathbf{V}^T)^{-1} = \begin{bmatrix} \frac{2\pi}{\Delta x} & 0 & 0 \\ 0 & \frac{\pi}{\Delta y} & 0 \\ 0 & -\frac{2\pi}{\Delta t} & \frac{4\pi}{\Delta t} \end{bmatrix}.$$

# General video sampling

Frequency periodicity grids $\Lambda^*$:




Inverse sampling grid $\Lambda^*$ for: a) Progressive video;
b) 2:1 interlaced video.

# General analog video reconstruction

***Analog video reconstruction***:

- Original analog signal $f_a(\mathbf{x}_t)$ recovery from $f(\mathbf{n})$:
  - the support area of the Fourier transform $F_a(\Omega_x, \Omega_y, \Omega_t)$ should be a subset of the unit cell of the inverse grid $\Lambda^*$.
- Perfect reconstruction by an ideal low-pass filter:
  - Its passband should be the unit cell $\mathcal{P}$ and the $\Lambda^*$ grid:

$$F_a(\mathbf{\Omega}) = \begin{cases} |\det \mathbf{V}| F(\mathbf{V}^T \mathbf{\Omega}), & \mathbf{\Omega} \in \mathcal{P} \\ 0, & \text{elsewhere.} \end{cases}$$

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# General analog video reconstruction

- Analog video reconstruction:

$$f_a(\mathbf{x}_t) = \sum_{\boldsymbol{n} \in \mathbb{Z}^3} f(\mathbf{n}) h(\mathbf{x}_t - \mathbf{V}\mathbf{n}).$$

- Impulse response of the ideal spatiotemporal low-pass interpolation filter:

$$h(\mathbf{x}_t) = \frac{|\mathrm{det}\mathbf{V}|}{(2\pi)^3} \int_{\mathrm{P}} e^{i\boldsymbol{\Omega}^{\mathrm{T}}\mathbf{x}_{\mathrm{t}}} \, d\boldsymbol{\Omega}.$$

# General analog video reconstruction

- For progressive video sampling:
  - the impulse response of the ideal video interpolation filter is the triple sinc function:

$$h(\mathbf{x}_t) = \frac{\sin(\frac{\pi}{\Delta x}x)}{\frac{\pi}{\Delta x}x} \frac{\sin(\frac{\pi}{\Delta y}y)}{\frac{\pi}{\Delta y}y} \frac{\sin(\frac{\pi}{\Delta t}t)}{\frac{\pi}{\Delta t}t}.$$

# Bibliography

[PIT2017] I. Pitas, “Digital video processing and analysis” , China Machine Press, 2017 (in Chinese).

[PIT2013] I. Pitas, “Digital Video and Television” , Createspace/Amazon, 2013.

[PIT2021] I. Pitas, “Computer vision”, Createspace/Amazon, in press.

[NIK2000] N. Nikolaidis and I. Pitas, “3D Image Processing Algorithms”, J. Wiley, 2000.

[PIT2000] I. Pitas, “Digital Image Processing Algorithms and Applications”, J. Wiley, 2000.

# Q & A

**Thank you very much for your attention!**

**More material in**
**http://icarus.csd.auth.gr/cvml-web-lecture-series/**

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