Lens design

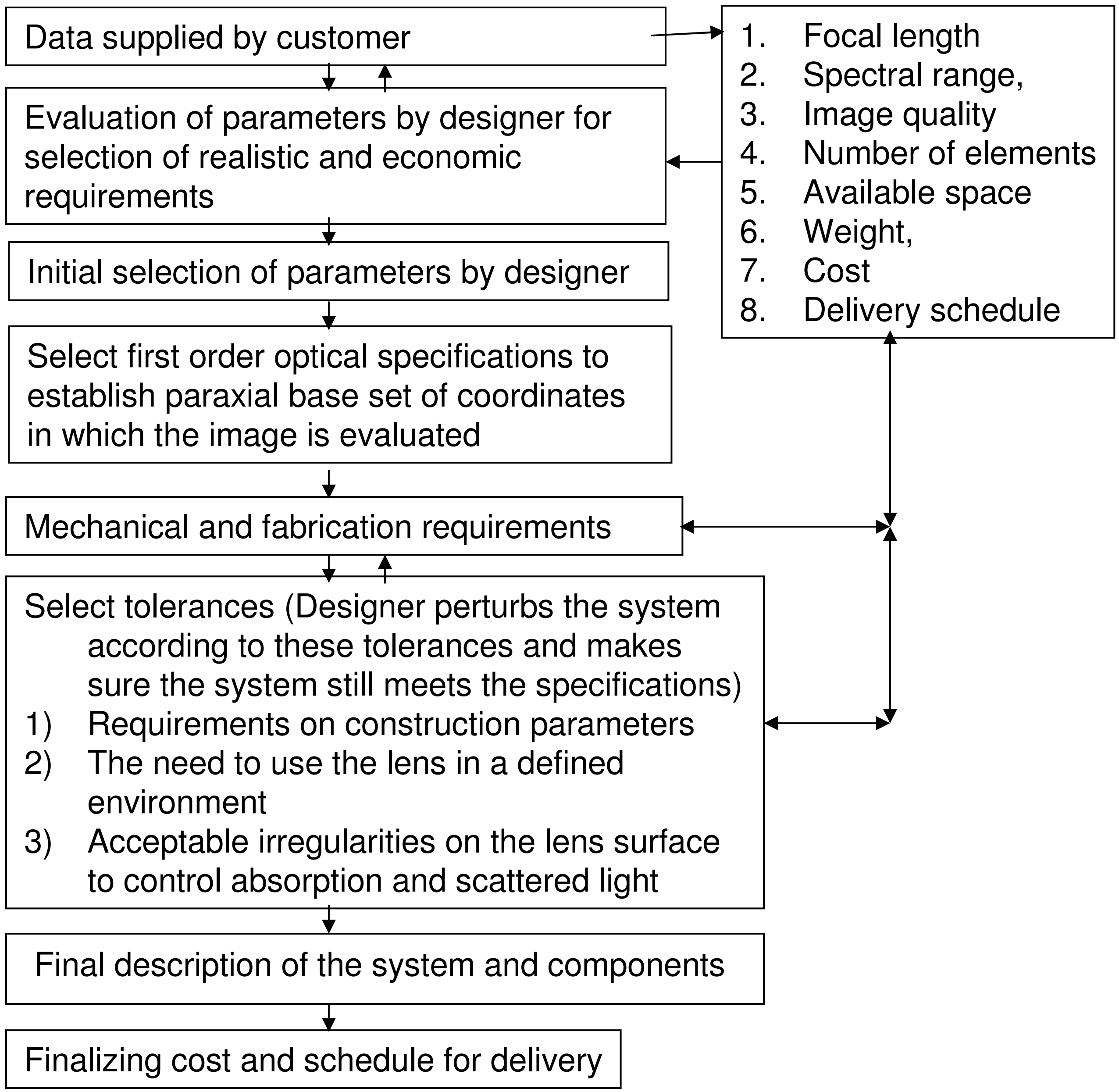
Some of the important topics needed to be addressed in a successful lens design project (R.R. Shannon: The Art and Science of Optical Design)

- Focal length (f)
- Field angle or field size
- F/number
- Numerical aperture (NA)
- Wavelength and spectral range
- Magnification and focusing range
- Zoom ranges
- Type of lenses
- Back focus
- Front focus
- Pupil locations
- Illumination
- Irradiance uniformity
  - Vignetting
  - Transmission
- Ghost images
- Distortion
- Variation with conjugates
- Variation with spectral region
- Interference with optical path
- Image quality
  - Aberrations
  - Resolution
  - Optical Transfer Function (OTF)
  - Modulation transfer function (MTF)
  - Energy concentration (Intensity pattern)
  - Effect of aperture stop
  - at various apertures
- Scattered light
- Polarization
- Veiling glare
- Light baffling
- Off-axis rejection
- Field stop definition
- Diffraction effects
- Tolerances
- Depth of focus
- Interface with variable aperture
- Interface with autofocus system
- Size and configuration
- Zoom Mechanization
- Focus mechanization
- Folding components
- Schedule and delivery time
- Optical interfacing with instruments
- Cost of
  - Design
  - prototype
  - Production
- Materials
  - Availability
  - Cost
  - Continued supply
  - Suitability for processing
  - Compatibility with operation conditions
  - Environmental considerations
  - Hazardous material
- Environment
  - Temperature range
  - Storage conditions
  - Atmospheric pressure
  - Humidity
  - Vibration and shock
- Availability of subcontractors
- Level of technology
- Weight
- Moment about mounting
- Coatings
  - Transmission
  - Reflectivity
  - Absorption
  - Availability
  - Risk
  - Environmental effects
  - Mechanical and optical quality
- Manufacturability
- Produecibility
- Manufacturing processes
- Manufacturability
- Produecibility
- Manufacturing processes
- Mounting processes
- Mounting interfaces
- Mechanical interfaces with instrument
- Detector
  - Photographic
  - Sampling array
  - Signal to noise
- Surface finish, cosmetics
- Beam parameters
- Radiation damage
- Irradiance damage
- Prior experience
- Track record
- Prior art
- Patentability
- Patent conflict situation
- Competitive situation
- Marketability
- Interface to other producers
- Lifetime of product
- Rate of production
- Liability issues
- Delay to market
- Timing of disclosure
- Integration with other products
- Customer view of product
- Styling
- Investment requirements and risks
- Funding and financial viability

Lens design parameters Starting a design

- Field (or object) size
- Axial aperture
  - Controls brightness of the image
  - Vignetting: deliberate reduction of irradiance by off axis by proper selection of element diameters. It is a tool to control aberrations
- Image size
- Design concerns
  - Image quality requirements
  - Mechanical layout
  - Material selection
  - Tolerances
  - **Definition of starting point**
- **Passage of rays through the system is studied with geometrical ray tracing. The result is image location.**
- **Image formation through combination (interference) of rays and bundles is studied with physical optics or diffraction optics. The result is image quality.**

Basic design steps



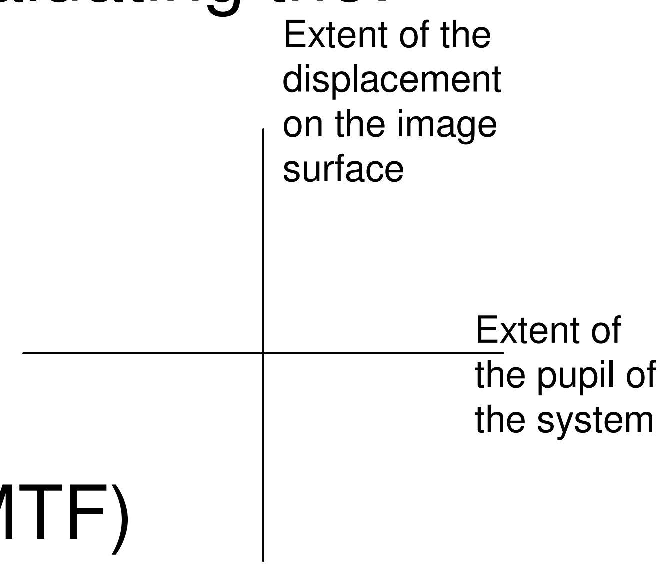
Detailed description of a lens

- Sequentially numbered set of spherical surfaces
  - Curvature
  - Thickness to the next surface or separation
  - Index of refraction of the medium after the surface
  - Surface shape
  - Orientation
  - Dimension
  - Symmetry
- Operating condition
- Use the operating manual of the software in use to enter these data

Merit functions used in design evaluation

Evaluation of a lens is done through sampling state of aberration of the lens by computing light distribution across the lens including diffraction effects. This is achieved by evaluating the:

1. Ray intercept plots
2. Spot diagrams
3. Point Spread Function (PSF)
4. Optical transfer function (OTF)
5. Modulation transfer function (MTF)



Ray Intercept Diagrams
A geometrical optics calculation

Spot Diagrams / Ray Scatter Diagrams A geometrical optics calculation

- They show symmetry of aberration

Point Spread Function (PSF)
A physical optics calculation

- Light intensity distribution in the diffraction image if the lens were made perfectly.
- It is simply image of a point object.

Optical Transfer Function (OTF) A physical optics calculation

- A functional representation of the spatial frequency response of the lens.
- OTF is a Fourier transform of the PSF
- Spatial frequency or wavenumber: number of wavelengths in a unit length (not time)
- OTF describes the contrast between images of different sinusoidal elements with specified spatial frequency
- Image analysis with OTF is equivalent to Frequency band analysis in communication

Modulation Transfer Function (MTF) A physical optics calculation

- MTF which is modulus of the OTF is a more interesting function to the lens users.

Completing a lens design

- Tolerances

OSLO introductory exercise- Landscape lens

- **Goal**: enter lens data and understand the optical performance of a simple lens. (Make sure the software has its initial settings)
- **Steps**:
  - **Lens entry**: convex-plano lens with displaced aperture stop behind the lens
  - **Lens drawing**: Set up the lens drawing conditions to show desired ray trajectories
  - **Optimization**: Optimize the lens so it has no coma, Focal length of 100, covers a field of +/- 20 degrees at an aperture of f/10
  - **Slider-wheel design**: attach sliders to parameters so you can analyze the trade-offs.
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Optimization

- Create the lens
- Set up optimization tasks
  - Define an error function that makes the focal length exactly 100 mm and eliminates the Seidel coma from the image.