Introduction to Arnoldi method

SF2524 - Matrix Computations for Large-scale Systems

Main eigenvalue algorithms in this course

- Fundamental eigenvalue techniques (Lecture 1)
- Arnoldi method (Lecture 2-3).

- QR-method (Lecture 8-9).

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- Fundamental eigenvalue techniques (Lecture 1)
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  Typically suitable when
  - we are interested in a small number of eigenvalues,
  - the matrix is large and sparse
  - Solvable size on current desktop $m \sim 10^6$ (depending on structure)
- QR-method (Lecture 8-9).
  Typically suitable when
  - we want to compute all eigenvalues,
  - the matrix does not have any particular easy structure.
  - Solvable size on current desktop $m \sim 1000$.

Agenda lecture 2

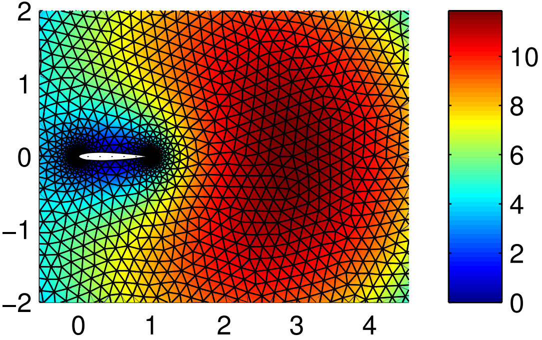
- Introduction to Arnoldi method
- Gram-Schmidt - efficiency and roundoff errors
- Derivation of Arnoldi method
- (Next lecture: Convergence characterization)

Large-scale example - finite-element method (1/2)

Laplace eigenvalue problem

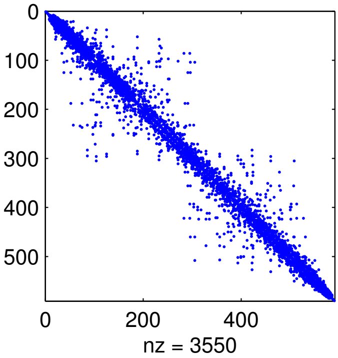
$$\Delta u = \lambda u$$

with Dirichlet boundary conditions outside wing profile.



Large-scale example - finite-element method (2/2)

$\Rightarrow$ Problem: Compute eigenvalues of matrix $A \in \mathbb{R}^{m\times m}$ where m large but few non-zero elements:



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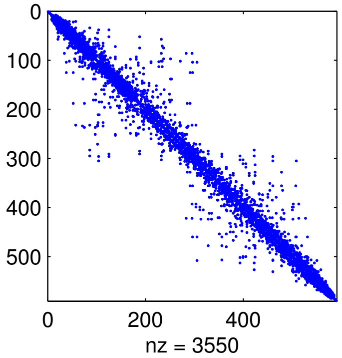

In MATLAB with very efficient QR-method:

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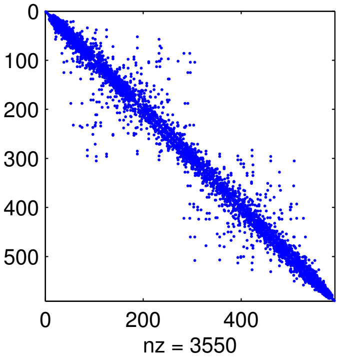

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More than 10 hours. ⇒ need a different method

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$$Q^T A Q z = \mu z$$

are called *Ritz pairs*.

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Justification of Arnoldi method

- Use Rayleigh-Ritz on $Q = (q_1, \ldots, q_n)$ and $Q^T Q = I$, where

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- Arnoldi method is a "clever" procedure to construct $H_n = Q^T AQ$.
- "Clever": We expand Q with one row in each iteration
  $\Rightarrow$ Iterate until we are happy.

Arnoldi method graphically

Graphical illustration of algorithm:

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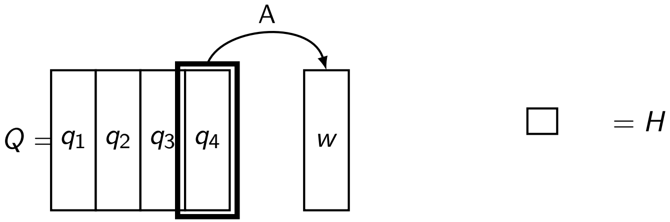

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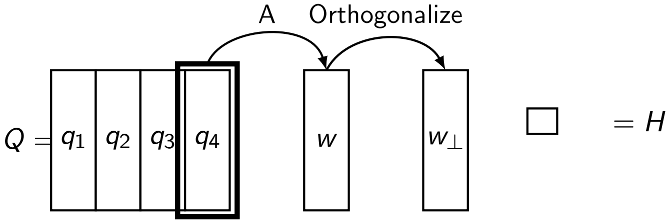

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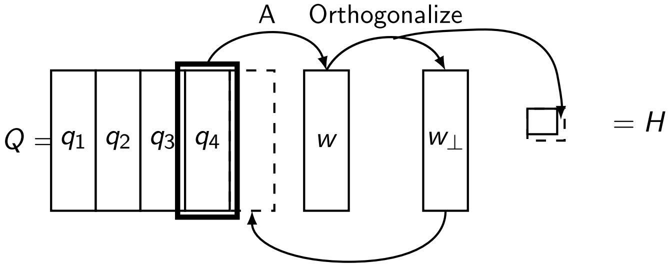

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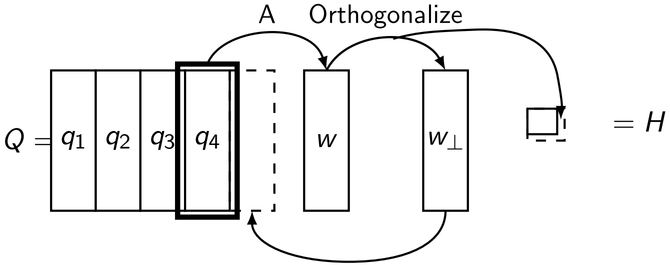

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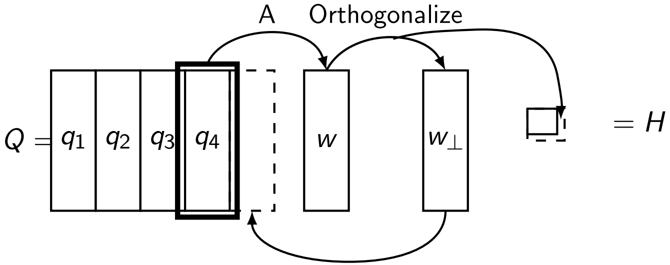

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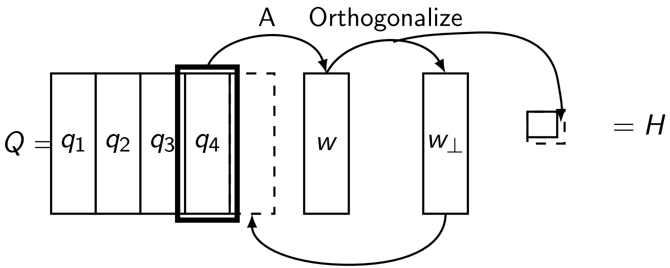

After iteration: Take eigenvalues of H as approximate eigenvalues.

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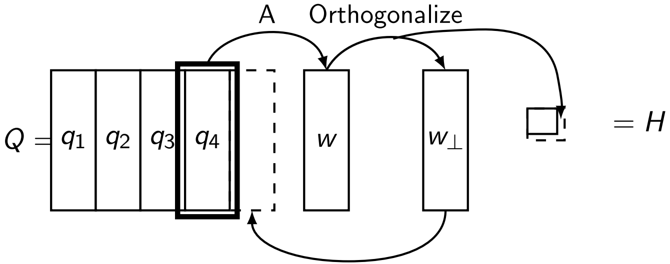

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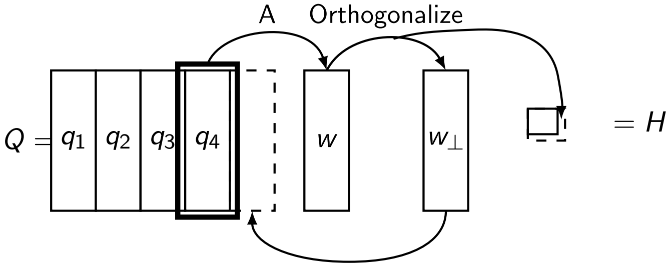

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We will now...

(1) derive a good orthogonalization procedure: variants of Gram-Schmidt,

(2) show that Arnoldi generates a Rayleigh-Ritz approximation,

(3) characterize the convergence (next lecture?).