```
class CV_EXPORTS_W Estimator {
        public:
            virtual ~Estimator() {}

            /** @brief Estimates camera parameters.

            @param features Features of images
            @param pairwise_matches Pairwise matches of images
            @param cameras Estimated camera parameters
            @return True in case of success, false otherwise
              */
            CV_WRAP_AS(apply)

            bool operator()(const std::vector<ImageFeatures> &features,
                            const std::vector<MatchesInfo> &pairwise_matches,
                            CV_OUT CV_IN_OUT std::vector<CameraParams> &cameras) {
                return estimate(features, pairwise_matches, cameras);
            }

        protected:
            /** @brief This method must implement camera parameters estimation logic in order
to make the wrapper
            detail::Estimator::operator()_ work.

            @param features Features of images
            @param pairwise_matches Pairwise matches of images
            @param cameras Estimated camera parameters
            @return True in case of success, false otherwise
              */
            virtual bool estimate(const std::vector<ImageFeatures> &features,
                                  const std::vector<MatchesInfo> &pairwise_matches,
                                  CV_OUT std::vector<CameraParams> &cameras) = 0;
        };

/** @brief Homography based rotation estimator.
  */
        class CV_EXPORTS_W HomographyBasedEstimator : public Estimator {
        public:
            CV_WRAP HomographyBasedEstimator(bool is_focals_estimated = false)
                    : is_focals_estimated_(is_focals_estimated) {}
```

```
        private:
            virtual bool estimate(const std::vector<ImageFeatures> &features,
                                  const std::vector<MatchesInfo> &pairwise_matches,
                                  std::vector<CameraParams> &cameras);

            bool is_focals_estimated_;
        };

/** @brief Affine transformation based estimator.

This estimator uses pairwise transformations estimated by matcher to estimate
final transformation for each camera.

@sa cv::detail::HomographyBasedEstimator
 */
        class CV_EXPORTS_W AffineBasedEstimator : public Estimator {
        public:
            CV_WRAP AffineBasedEstimator() {}

        private:
            virtual bool estimate(const std::vector<ImageFeatures> &features,
                                  const std::vector<MatchesInfo> &pairwise_matches,
                                  std::vector<CameraParams> &cameras);
        };
bool HomographyBasedEstimator::estimate(
                const std::vector<ImageFeatures> &features,
                const std::vector<MatchesInfo> &pairwise_matches,
                std::vector<CameraParams> &cameras) {
            LOGLN("Estimating rotations...");
#if ENABLE_LOG
            int64 t = getTickCount();
#endif

            const int num_images = static_cast<int>(features.size());

            if (!is_focals_estimated_) {
                // Estimate focal length and set it for all cameras
                std::vector<double> focals;
                cv::vi_detail::estimateFocal(features, pairwise_matches, focals);
                cameras.assign(num_images, CameraParams());
                for (int i = 0; i < num_images; ++i)cameras[i].focal = focals[i];
```

```
//                          printValue(cameras, "a22");
                    } else {
                          MATH21_ASSERT(0, "debug");
                          for (int i = 0; i < num_images; ++i) {
                                cameras[i].ppx -= 0.5 * features[i].img_size.width;
                                cameras[i].ppy -= 0.5 * features[i].img_size.height;
                          }
                    }

                    // Restore global motion
                    Graph span_tree;
                    std::vector<int> span_tree_centers;
                    vi_detail::findMaxSpanningTree(num_images,       pairwise_matches,       span_tree,
span_tree_centers);
                    span_tree.walkBreadthFirst(span_tree_centers[0],             CalcRotation(num_images,
pairwise_matches, cameras));

                    // As calculations were performed under assumption that p.p. is in image center
                    for (int i = 0; i < num_images; ++i) {
                          cameras[i].ppx += 0.5 * features[i].img_size.width;
                          cameras[i].ppy += 0.5 * features[i].img_size.height;
                    }

                    LOGLN("Estimating rotations, time: " << ((getTickCount() - t) / getTickFrequency()) << "
sec");
                    return true;
              }
              struct CalcRotation {
                    CalcRotation(int _num_images, const std::vector<MatchesInfo> &_pairwise_matches,
                                      std::vector<CameraParams> &_cameras)
                                : num_images(_num_images),  pairwise_matches(&_pairwise_matches[0]),
cameras(&_cameras[0]) {}

                    void operator()(const GraphEdge &edge) {
                          int pair_idx = edge.from * num_images + edge.to;

                          Mat_<double> K_from = Mat::eye(3, 3, CV_64F);
                          K_from(0, 0) = cameras[edge.from].focal;
                          K_from(1, 1) = cameras[edge.from].focal * cameras[edge.from].aspect;
                          K_from(0, 2) = cameras[edge.from].ppx;
                          K_from(1, 2) = cameras[edge.from].ppy;
```

```
            Mat_<double> K_to = Mat::eye(3, 3, CV_64F);
            K_to(0, 0) = cameras[edge.to].focal;
            K_to(1, 1) = cameras[edge.to].focal * cameras[edge.to].aspect;
            K_to(0, 2) = cameras[edge.to].ppx;
            K_to(1, 2) = cameras[edge.to].ppy;

            Mat R = K_from.inv() * pairwise_matches[pair_idx].H.inv() * K_to;
            cameras[edge.to].R = cameras[edge.from].R * R;
        }

        int num_images;
        const MatchesInfo *pairwise_matches;
        CameraParams *cameras;
    };
bool AffineBasedEstimator::estimate(const std::vector<ImageFeatures> &features,
                                    const           std::vector<MatchesInfo>
&pairwise_matches,
                                    std::vector<CameraParams> &cameras) {
        cameras.assign(features.size(), CameraParams());
        const int num_images = static_cast<int>(features.size());

        // find maximum spaning tree on pairwise matches
        Graph span_tree;
        std::vector<int> span_tree_centers;
        // uses number of inliers as weights
        vi_detail::findMaxSpanningTree(num_images, pairwise_matches, span_tree,
                                       span_tree_centers);

        // compute final transform by chaining H together
        span_tree.walkBreadthFirst(
                span_tree_centers[0],
                CalcAffineTransform(num_images, pairwise_matches, cameras));
        // this estimator never fails
        return true;
    }
/**
 * @brief Functor calculating final transformation by chaining linear transformations
 */
    struct CalcAffineTransform {
        CalcAffineTransform(int _num_images,
```

```
                                        const std::vector<MatchesInfo> &_pairwise_matches,
                                        std::vector<CameraParams> &_cameras)
                              :  num_images(_num_images),  pairwise_matches(&_pairwise_matches[0]),
cameras(&_cameras[0]) {}

                void operator()(const GraphEdge &edge) {
                    int pair_idx = edge.from * num_images + edge.to;
                    cameras[edge.to].R = cameras[edge.from].R * pairwise_matches[pair_idx].H;
                }

                int num_images;
                const MatchesInfo *pairwise_matches;
                CameraParams *cameras;
        };
class Graph {
        public:
                Graph(int num_vertices = 0) { create(num_vertices); }

                void create(int num_vertices) { edges_.assign(num_vertices, std::list<GraphEdge>()); }

                int numVertices() const { return static_cast<int>(edges_.size()); }

                void addEdge(int from, int to, float weight);

                template<typename B>
                B forEach(B body) const;

                template<typename B>
                B walkBreadthFirst(int from, B body) const;

        private:
                std::vector<std::list<GraphEdge> > edges_;
        };
struct GraphEdge {
                GraphEdge(int from, int to, float weight);

                bool operator<(const GraphEdge &other) const { return weight < other.weight; }

                bool operator>(const GraphEdge &other) const { return weight > other.weight; }

                int from, to;
```

```
            float weight;
        };
inline GraphEdge::GraphEdge(int _from, int _to, float _weight) : from(_from), to(_to), weight(_weight)
{}
void Graph::addEdge(int from, int to, float weight) {
            edges_[from].push_back(GraphEdge(from, to, weight));
        }
template<typename B>
        B Graph::forEach(B body) const {
            for (int i = 0; i < numVertices(); ++i) {
                std::list<GraphEdge>::const_iterator edge = edges_[i].begin();
                for (; edge != edges_[i].end(); ++edge)
                    body(*edge);
            }
            return body;
        }


        template<typename B>
        B Graph::walkBreadthFirst(int from, B body) const {
            std::vector<bool> was(numVertices(), false);
            std::queue<int> vertices;

            was[from] = true;
            vertices.push(from);

            while (!vertices.empty()) {
                int vertex = vertices.front();
                vertices.pop();
                std::list<GraphEdge>::const_iterator edge = edges_[vertex].begin();
                for (; edge != edges_[vertex].end(); ++edge) {
                    if (!was[edge->to]) {
                        body(*edge);
                        was[edge->to] = true;
                        vertices.push(edge->to);
                    }
                }
            }
            return body;
        }
```

```
void focalsFromHomography(const Mat &H, double &f0, double &f1, bool &f0_ok, bool &f1_ok) {
        CV_Assert(H.type() == CV_64F && H.size() == Size(3, 3));

        const double *h = H.ptr<double>();

        double d1, d2; // Denominators
        double v1, v2; // Focal squares value candidates

        f1_ok = true;
        d1 = h[6] * h[7];
        d2 = (h[7] - h[6]) * (h[7] + h[6]);
        v1 = -(h[0] * h[1] + h[3] * h[4]) / d1;
        v2 = (h[0] * h[0] + h[3] * h[3] - h[1] * h[1] - h[4] * h[4]) / d2;
        if (v1 < v2) std::swap(v1, v2);
        if (v1 > 0 && v2 > 0) f1 = std::sqrt(std::abs(d1) > std::abs(d2) ? v1 : v2);
        else if (v1 > 0) f1 = std::sqrt(v1);
        else f1_ok = false;

        f0_ok = true;
        d1 = h[0] * h[3] + h[1] * h[4];
        d2 = h[0] * h[0] + h[1] * h[1] - h[3] * h[3] - h[4] * h[4];
        v1 = -h[2] * h[5] / d1;
        v2 = (h[5] * h[5] - h[2] * h[2]) / d2;
        if (v1 < v2) std::swap(v1, v2);
        if (v1 > 0 && v2 > 0) f0 = std::sqrt(std::abs(d1) > std::abs(d2) ? v1 : v2);
        else if (v1 > 0) f0 = std::sqrt(v1);
        else f0_ok = false;
    }


    void estimateFocal(const std::vector<ImageFeatures> &features, const
std::vector<MatchesInfo> &pairwise_matches,
                std::vector<double> &focals) {
        const int num_images = static_cast<int>(features.size());
        focals.resize(num_images);

        std::vector<double> all_focals;

        for (int i = 0; i < num_images; ++i) {
            for (int j = 0; j < num_images; ++j) {
                const MatchesInfo &m = pairwise_matches[i * num_images + j];
```

```
                if (m.H.empty())
                    continue;
                double f0, f1;
                bool f0ok, f1ok;
                focalsFromHomography(m.H, f0, f1, f0ok, f1ok);
                if (f0ok && f1ok)
                    all_focals.push_back(std::sqrt(f0 * f1));
            }
        }

        if (static_cast<int>(all_focals.size()) >= num_images - 1) {
            double median;

            std::sort(all_focals.begin(), all_focals.end());
            if (all_focals.size() % 2 == 1)
                median = all_focals[all_focals.size() / 2];
            else
                median = (all_focals[all_focals.size() / 2 - 1] + all_focals[all_focals.size() / 2])
* 0.5;

            for (int i = 0; i < num_images; ++i)
                focals[i] = median;
        } else {
            LOGLN("Can't estimate focal length, will use naive approach");
            double focals_sum = 0;
            for (int i = 0; i < num_images; ++i)
                focals_sum += features[i].img_size.width + features[i].img_size.height;
            for (int i = 0; i < num_images; ++i)
                focals[i] = focals_sum / num_images;
        }
    }
```

```
void findMaxSpanningTree(int num_images, const std::vector<MatchesInfo> &pairwise_matches,
                                   Graph &span_tree, std::vector<int> &centers) {
        Graph graph(num_images);
        std::vector<GraphEdge> edges;

        // Construct images graph and remember its edges
        for (int i = 0; i < num_images; ++i) {
            for (int j = 0; j < num_images; ++j) {
                if (pairwise_matches[i * num_images + j].H.empty())
                    continue;
                float   conf   =   static_cast<float>(pairwise_matches[i   *   num_images   +
j].num_inliers);
                graph.addEdge(i, j, conf);
                edges.push_back(GraphEdge(i, j, conf));
            }
        }

        DisjointSets comps(num_images);
        span_tree.create(num_images);
        std::vector<int> span_tree_powers(num_images, 0);

        // Find maximum spanning tree
        sort(edges.begin(), edges.end(), std::greater<GraphEdge>());
        for (size_t i = 0; i < edges.size(); ++i) {
            int comp1 = comps.findSetByElem(edges[i].from);
            int comp2 = comps.findSetByElem(edges[i].to);
            if (comp1 != comp2) {
                comps.mergeSets(comp1, comp2);
                span_tree.addEdge(edges[i].from, edges[i].to, edges[i].weight);
                span_tree.addEdge(edges[i].to, edges[i].from, edges[i].weight);
                span_tree_powers[edges[i].from]++;
                span_tree_powers[edges[i].to]++;
            }
        }

        // Find spanning tree leafs
        std::vector<int> span_tree_leafs;
        for (int i = 0; i < num_images; ++i)
            if (span_tree_powers[i] == 1)
                span_tree_leafs.push_back(i);
```

```
    // Find maximum distance from each spanning tree vertex
    std::vector<int> max_dists(num_images, 0);
    std::vector<int> cur_dists;
    for (size_t i = 0; i < span_tree_leafs.size(); ++i) {
        cur_dists.assign(num_images, 0);
        span_tree.walkBreadthFirst(span_tree_leafs[i], IncDistance(cur_dists));
        for (int j = 0; j < num_images; ++j)
            max_dists[j] = std::max(max_dists[j], cur_dists[j]);
    }

    // Find min-max distance
    int min_max_dist = max_dists[0];
    for (int i = 1; i < num_images; ++i)
        if (min_max_dist > max_dists[i])
            min_max_dist = max_dists[i];

    // Find spanning tree centers
    centers.clear();
    for (int i = 0; i < num_images; ++i)
        if (max_dists[i] == min_max_dist)
            centers.push_back(i);
    CV_Assert(centers.size() > 0 && centers.size() <= 2);
}
```